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METACONCEPTUALLY-ENHANCED SIMULATION-BASED INQUIRY
LEARNING: EFFECTS ON THE 8TH GRADE STUDENTS' CONCEPTUAL CHANGE
AND SCIENCE EPISTEMOLOGICAL BELIEFS

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KUN HUANG
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METACONCEPTUALLY-ENHANCED SIMULATION-BASED INQUIRY
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AND SCIENCE EPISTEMOLOGICAL BELIEFS

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BY

Dr. Xun Ge, Chair

Dr. Howard Crowson

Dr. Deniz Eseryel

Dr. Patricia Hardré

Dr. Timothy Laubach

Dr. Raymond Miller

DEDICATION

This dissertation is dedicated to my family for their unconditional love.

To Jun: thank you for your love, patience, and sacrifice. Your action speaks louder than words. Never in my entire PhD process did you lose your patience or discourage me in what I was doing. You supported me in every possible way. I am grateful to have you as my lifetime partner.

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ABSTRACT

Two quasi-experimental studies (a pilot study and a main study) were carried out to investigate the effects of metaconceptually-enhanced, simulation-based inquiry learning on the 8th grade students' conceptual change in science and their development of science epistemological beliefs. In each of the studies, the students engaged in simulation-based science inquiry learning activities over a period of two weeks, supported by different simulation guides. One guide was enhanced with metaconceptual intervention while the other was not. The findings from both pilot study and main study led to the following conclusions: (a) metaconceptual intervention can enhance simulation-based learning by significantly reducing science misconceptions, but it is not as effective in changing students' mental models consisting of multiple interrelated key concepts; (b) students' beliefs about the *speed of learning* and the *construction of knowledge* are strong predictors of their conceptual change and learning outcomes; (c) epistemologically more advanced students do not benefit more from the metaconceptual intervention than those with less mature epistemological beliefs; (d) inquiry learning and metaconceptual intervention have limitations in their promoting of students' development of science epistemological beliefs. Theoretical and practical implications as well as directions for future research are discussed.

CHAPTER 1: INTRODUCTION

Terina, a fifth grader knows that the earth is round. When questioned about why the earth looks flat and what the real shape of the earth is, she answers, “Round, like a thick pancake” (Vosniadou & Brewer, 1992, p. 548). This case illustrates how Terina’s personal experience, that the earth appears to be flat, might interfere with her learning in the science classroom. Starting from the 1970s, science educators came to realize that students bring to science classrooms numerous misconceptions developed over their years of life experience. When learning the often counter-intuitive science concepts, especially those that cannot be easily observed (National Research Council, 2000), students often have difficulty reconciling the new information with their alternative conceptions, resulting in isolated and fragmental understanding (Hestenes, Wells, & Swackhamer, 1992). Lacking a coherent and systematic knowledge base, many students have to rely on rote memorization to solve science problems.

Now let us turn to a high school science classroom. Ms. Johnson, a science teacher, tries to encourage her students to discuss a question raised earlier by a student. While some students are apparently engaged in discussing and sharing their views with each other, Michael, a student, grumbles to his neighbor, “I don’t understand why we have to do this. Why can’t she just tell us the answer? There is only one right answer anyway!” Michael’s reaction reveals some underlying beliefs about the nature of knowledge and learning (Hofer & Pintrich, 1997), which are common among students and affect their learning approach and learning outcomes in a profound way.

The two vignettes above illustrate two very important constructs in today’s science education – conceptual change and science epistemological beliefs. Conceptual

change refers to the development of one's naïve ideas toward scientific conceptions; Science epistemological beliefs are an individual's beliefs about the nature of knowledge and learning in science. Science researchers and educators have recognized the problems of misconceptions in science and various complications associated with naïve epistemological beliefs, and thus made it an important agenda item to actively promote conceptual change and develop mature epistemological beliefs among students (Pintrich, Marx, & Boyle, 1993; Sinatra, 2005; Vosniadou, 2007b; Vosniadou & Brewer, 1992).

In a broader picture, as a country that has led the world in science, technology, engineering and mathematics (STEM), the United States has been falling behind in STEM education when compared with other industrialized countries (Kuenzi, 2008). According to a 2003 international survey on science literacy of 15-year-olds, the United States ranked 24th among the 40 participating countries (Kuenzi, 2008). When students in the United States reach college level, 30% of freshmen need remedial science classes before they can take college-level courses (National Science Board, 2007). To maintain its competitive edge in an era of knowledge economy, the nation has taken up STEM education as a top priority (National Science Board, 2007). In such a context, the National Research Council (2005) has recommended three important principles of science learning and instruction: (a) addressing students' preconceptions, (b) promoting students' knowledge of what it means to *do science*, and (c) emphasizing metacognition. These three principles are precisely what this study aimed at investigating. Specifically, this study was intended to examine ways to facilitate students' conceptual change and epistemological development in science, while at the same time exploring the complex interrelationships among various constructs involved in this process.

Study Background

Ever since the discovery of problems with student misconceptions in science learning in the 1970's, science misconceptions have become the main focus to be addressed in science education. Conceptual change, although bearing different definitions by different researchers, has been generally recognized as an important learning outcome that cannot be achieved by conventional teaching strategies that are characterized by directly imparting knowledge to students without addressing their preconceptions (Wandersee, Mintzes, & Novak, 1994). As a result, different conceptual change models have been proposed. Among them, the most influential one was proposed by Strike and Posner (1982), who were inspired by Kuhn's (1996) paradigm shift theory from his observation of scientific revolution in the history of science. Drawing connections between conceptual change in science learning and theory changes in the science community, Strike and Posner (1982) proposed four essential conditions required for conceptual change: 1) the learners must be dissatisfied with their existing conceptions; 2) there must be a new alternative conception that is intelligible to the learner; 3) the new conception must be plausible; and 4) the new conception must also be fruitful.

Strike and Posner's (1982) model, as well as other conceptual change strategies along the same line, has provided practical guidelines for science education researchers and thus led to the early implementation and investigation of instructional interventions. The interventions often confront learners with anomalous data or contradictory information, which supposedly induces cognitive conflict in learners' minds. Learners are expected to detect the conflict, be dissatisfied with it, compare it with new alternatives, and resolve the conflict, which leads to conceptual change in the end. However, often

students failed to achieve conceptual change as researchers had expected. In some cases, conceptual change had hardly occurred. Learners did not react to cognitive conflict at all or they reacted at a superficial level (Chan, Burtis, & Bereiter, 1997; Chinn & Malhotra, 2002; Limon, 2001). When conceptual change did occur after an intervention, the change did not last long and learners were soon found to revert back to their initial preconceptions (e.g., Hynd, 1998; Tao & Gunstone, 1999b).

As researchers reflected on the reasons why conceptual change did not always occur nor was it sustained, they questioned the assumption that students would think like scientists as they learn science. This is an assumption which underlay many early instructional interventions (Caravita & Halldén, 1994; Greiffenhagen & Sherman, 2006; Schnotz, Vosniadou, & Carretero, 1999). With this assumption, students are assumed to be able to plan and conduct experiments, evaluate results, identify inconsistencies, search for evidence, and give up their own ideas in favor of some competing scientific conceptions. However, in reality, students often do not treat their ideas as a thinking object like scientists do. They are often unaware of their existing ideas on a topic, nor do they actively track the development of their ideas through continuous monitoring and evaluation. To cite Murphy and Mason (2006), students are merely thinking *with*, but not *about* their conceptions.

Another criticism of the traditional models of conceptual change revealed another, yet more fundamental, aspect of the notion of thinking like a scientist. Questioning the cold, overly rational tradition of the conceptual change research that focused exclusively on the cognitive aspect of the change process, some motivation researchers introduced a “warming trend” (Sinatra, 2005, p. 107) into the conceptual change research, which

suggested taking motivational and affective factors into consideration. This group of researchers postulated that motivational beliefs, including individuals' epistemological beliefs, that is, beliefs about the nature of knowledge and knowing (Hofer & Pintrich, 1997), could all play significant roles in conceptual change. Some empirical evidence revealed the link between learners' epistemological beliefs and conceptual change learning outcomes (e.g., Qian & Alvermann, 1995; Windschitl, 1997).

The two criticisms above on the traditional models of conceptual change converge to suggest that simply exposing learners to cognitive conflict is not adequate to bring about conceptual change. The process of conceptual change is a process of becoming more like a scientist, which involves at least two important aspects: (a) development of mature beliefs about knowledge and learning; and (b) intentional effort to engage in a metaconceptual level of thinking, that is, thinking *about* the development of one's conceptions. Moreover, it is very likely that these two aspects are not mutually exclusive, as there is evidence suggesting that those with more sophisticated epistemological beliefs are more likely to demonstrate metaconceptual level of thinking (e.g., Stathopoulou & Vosniadou, 2007). Conversely, engaging in reflective discourse may also help individuals' epistemological development (Lam & Chan, 2008; Smith, Maclin, Houghton, & Hennessey, 2000).

A closer look at the literature on epistemological beliefs also reveals that, in addition to their effects on conceptual change, the improvement of epistemological beliefs itself is an important learning goal. In their early studies on post-adolescent epistemological development, Kitchener and King (1981) theorized seven epistemological development stages with increasing maturity. While the ultimate goal is

to help individuals to reach the highest stage (stage 7), King and Kitchener (2004) observed that the majority of college students stay at the fourth stage, which is characterized by the inability to link evidence to conclusions in the face of ill-structured, controversial problems that require one's reflective judgment. Apparently, more research is needed to advance students' epistemological beliefs to a higher level.

Epistemological beliefs have traditionally been examined as a trait-like construct which develops only as one matures through years of education and life experience. In recent years, however, researchers have experimented with instructional interventions to foster the development of students' epistemological beliefs, particularly in the domain of science, and several studies have yielded positive findings (Conley, Pintrich, Vekiri, & Harrison, 2004; Lam & Chan, 2008; Smith, et al., 2000). Most of the interventions engaged learners in certain inquiry learning activities, in which students actively constructed knowledge by hands-on experimentation and reflective discourse. These studies shed light on the possibility of advancing epistemological development through thoughtfully designed instructional interventions.

Therefore, with conceptual change being influenced by individuals' epistemological beliefs and metacognitive thinking, with epistemological beliefs being a possible mediator for conceptual change, and with the development of epistemological beliefs being a learning goal itself, we return to our original question: How can we promote conceptual change and epistemological development?

There is yet another layer to add to the complexity of the above question. With the advance of technology in today's society, and with the increasing need to engage students in scientific inquiry, computer-based simulations have increasingly been used as

cognitive tools to support science learning. These pedagogical tools are relatively new in science classrooms, and research up to this point is yet to provide sufficient guidelines on the effective use of computer simulations to facilitate conceptual change and epistemological development. As such, this research was deliberately situated in the context of inquiry learning with computer-based simulations, for the purpose of investigating potential instructional interventions to promote conceptual change and epistemological development in science.

Problem Statement

As stated earlier, this study focused on conceptual change and its closely related belief change as two important learning outcomes in the context of simulation-based science inquiry. Particularly, this study implemented metaconceptual intervention aiming at stimulating students' metaconceptual thinking in their simulation-based inquiry and examining how the interventions affected students' conceptual changes as well as the development of their science epistemological beliefs.

Metaconceptual thinking is one of the characteristics of *thinking like a scientist*. Often termed as *metaconceptual awareness*, metaconceptual thinking has been emphasized by many researchers as one of the key factors in promoting conceptual change (Murphy & Mason, 2006; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). Yet, few studies have explicitly examined the effect of metaconceptual thinking on conceptual change, especially within a simulation-based inquiry learning environment. Therefore, this study asked whether metaconceptually-enhanced, simulation-based inquiry learning would promote better conceptual change when compared with simulation-based inquiry learning by itself. Similarly, since

epistemological belief is another important factor in conceptual change, this study was also designed to assess the role of students' general epistemological beliefs in conceptual change in a simulation-based inquiry learning environment, with or without metaconceptual intervention.

In addition, this study also sought to investigate whether metaconceptual intervention implemented in a simulation-based learning environment would help advance learners' science epistemological beliefs.

Significance of the Study

This study potentially has both theoretical and practical significance. Theoretically, the findings from this study may contribute to our knowledge base by revealing the interrelationships among several important constructs in science education and educational psychology – conceptual change, epistemological beliefs, metaconceptual thinking, and inquiry learning. While each of these constructs has been studied, their interrelationships have rarely been simultaneously examined, especially in a simulation-based inquiry learning environment. Specifically, the findings in this study were expected to demonstrate the effects of learners' epistemological beliefs and metaconceptual intervention on conceptual change in simulation-based inquiry learning. The findings may also help us to understand the relationship between learners' epistemological beliefs and metaconceptual intervention. Moreover, the study may provide evidence as to whether learners' epistemological beliefs in science are malleable through simulation-based inquiry and metaconceptual intervention. Most existing studies (e.g., Biemans & Simons, 1996; Mikkila-Erdmann, 2001; Qian & Alvermann, 2000) were conducted in a lab setting and for a relatively short period of time. By comparison,

this study was conducted in naturalistic science classrooms over a relatively longer period of time in the hope of building upon past research and yielding fruitful results, from which we can draw practical implications for educational practice.

Practically, helping students to face and overcome their misconceptions in science is an important goal in science education. Yet, it points to the need to develop more sophisticated epistemological beliefs and advance metaconceptual skills in science education, which is an arduous undertaking for science education. These educational goals become more critical as the nation is actively promoting STEM education and devoting a significant amount of energy, time and resources to improve the outcomes (National Science Board, 2007). The findings of this study may provide important guidelines for teachers and instructional designers to design and implement simulation-based inquiries that will facilitate students' conceptual change and epistemological development.

CHAPTER 2: LITERATURE REVIEW

This review first provides a broad overview of the three major constructs in this study: conceptual change, epistemological beliefs, and metaconceptual thinking. The general overview is followed by a more focused literature review of the relations among the constructs which set the stage for the study. Next, the review discusses relevant literature on the situating context of this study – simulation-based inquiry learning environment. At the end of the chapter, research questions are presented.

Understanding the Background: Overview of the Constructs

Conceptual Change

Conceptual change originated from two lines of research – science education and developmental psychology. In recent years, new schools of thoughts started to influence conceptual change research as well as educational research in general (a subset of metacognition that is related to one's conceptual understanding, Lave & Wenger, 1991; Pintrich, et al., 1993). This section first reviews the science education and developmental psychology traditions of conceptual change, and then introduces the new perspectives – motivational/affective and sociocultural perspectives.

Science education tradition. The term conceptual change originally came from studies on the history and philosophy of science. Kuhn (1996), in his analysis of theory changes in the history of science, distinguished between normal science and scientific revolution. Normal science is mainly knowledge accumulation, whereas scientific revolution necessitates radical revisions of existing scientific beliefs or practice, leading to a paradigm shift.

When science educators found the problem of students' misconceptions, Kuhn's work inspired them. Strike and Posner (1982) drew connections between conceptual change in science learning and theory change in the science community, and proposed four conditions for conceptual change: (a) the learner must be dissatisfied with his/her existing conceptions; (b) there must be a new alternative conception that is intelligible to the learner; (c) the new conception must be plausible; and (d) the new conception must also be fruitful. The model became very influential and has been the leading paradigm in the field for a long time. Following this model, instruction is often designed to induce learners' dissatisfaction with their existing conceptions by creating certain "cognitive conflict." The cognitive conflict can be induced by refutational texts that explicitly refute science misconceptions, by having students perform experiments to examine contradictory results, or by human interactions in which misconceptions may be exposed and confronted (Limon, 2001).

Over time Strike and Posner's (1982) classic model met several challenges. The controversial results from research studies led to the criticism of the model's underlying metaphor of student as scientist (Caravita & Halldén, 1994; Greiffenhagen & Sherman, 2006; Schnotz, et al., 1999), which assumes that students can engage in science learning like scientists who rationally examine deficiencies of their own ideas and evaluate and adopt new possible alternatives. In reality, however, students are not like scientists. In the face of an intended cognitive conflict, many students do not realize the conflict or feel dissatisfied with their naïve conceptions (Chinn & Malhotra, 2002; D. Kuhn & Lao, 1998; Vosniadou, 1994). In her critical appraisal of the cognitive conflict as conceptual change strategy, Limon (2001) noted that cognitive conflict alone cannot guarantee successful

conceptual change. It should be coupled with additional strategies to take care of other factors that may come into play, such as motivation, epistemological beliefs, prior knowledge, values and attitudes, social factors, etc.

Another challenge to the model is its “replacement” view, that conceptual change entails the replacement of misconceptions with scientific conceptions. Evidence suggests that alternative and scientific conceptions may coexist at the same time (Pozo, Gomez, & Sanz, 1999; Spada, 1994; Tao & Gunstone, 1999b).

Cognitive/developmental psychology tradition. Whereas the science education approach drew inferences from the history of science without referring to the cognitive structures underlying conceptual change, cognitive/developmental psychologists placed focus on mental states and provided more insights into the nature and process of conceptual change.

From her studies on children learning biology, Carey (1985) concluded that children’s intuitive knowledge has theory-like, coherent structure and that conceptual change requires “strong” reconstruction of the structure. Similarly, Vosniadou and Brewer (1992) found from their studies on elementary children learning basic astronomy that children at an early age develop a certain “framework theory” to interpret their daily experience. The framework contains “basic ontological and epistemological presuppositions about the nature of physical objects and the way they function in the physical world” (p. 64). It shapes children’s understanding when they learn. When new information is at odds with their framework theory, children construct so-called synthetic models (e.g., the earth as a pancake) to reconcile the new information with the framework theory. Conceptual change in this sense is not the instant replacement of alternative

conceptions, but rather a gradual process of the reorganization of the initial explanatory framework into scientific conceptualization.

diSessa (1983, 1988) does not agree that naïve knowledge is coherent. His “knowledge in pieces” view argues that intuitive knowledge contains fragmented mental entities gained from daily experiences (e.g., force as a mover) (diSessa, 1983), and conceptual change is achieved when learners organize and configure these mental entities into a coherent whole (diSessa, 2002).

Still another explanation was proposed by Chi, Slotta and de Leeuw (1994), that misconception is the result of incorrect mental assignment of a concept into a wrong ontological category (e.g., heat as “matter” instead of a “process”). Conceptual change is thus the shift of a concept to its correct ontological category. In their effort to address student misconceptions on the topic of electric current, Slotta and Chi (2006) trained students to understand and distinguish different ontological categories, and found positive results from the training. However, Vosniadou(2002) questioned this perspective by arguing that ontological shift might be just one case of the many kinds of conceptual change, and that the proposed ontological categories lacked theoretical evidence.

The warming trend: Motivational and affective factors. Questioning the sole focus of conceptual change research on cognition, Pintrich and colleagues (Pintrich, 1999; Pintrich, et al., 1993) advocated the consideration of motivational constructs and classroom contextual factors and discussed the potential relationship between conceptual change and goal orientations, interest and values, self-efficacy, control beliefs, and epistemological beliefs. The “warming trend” started to emerge (Sinatra, 2005) as more and more conceptual change research involved motivational and affective factors in

investigation. The link between conceptual change and motivational factors such as goal orientations (Linnenbrink & Pintrich, 2002; Sinatra & Mason, 2008) and interest (Andre & Windschitl, 2003; Pintrich, 1999) have been explored. Incorporating these additional factors in conceptual change, Sinatra and Pintrich (2003) proposed an intentional conceptual change model, and defined it as “goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge” (p.6).

Sociocultural perspectives. Whereas Pintrich et al. (1993) consider classroom contextual factors as potential moderators between motivational beliefs and conceptual change, the sociocultural perspective pushes contextual factors to the center stage of conceptual change. Researchers from this camp believe that cognitive structure is not the only construct when studying conceptual change and they zoom out the lens from individual learners to the learner community and the surrounding environment (Greeno & The Middle School Mathematics Through Applications Project Group, 1998; Wilson & Myers, 1999). Sociocultural factors like the role of a teacher (Chinn, 1998; Kelly & Green, 1998) and group culture (Gorodetsky & Keiny, 2002; Moje & Shepardson, 1998) have been found to affect conceptual change in different ways. Theorists such as Caravita and Halldén (1994) argue that learning is situated, and that difficulty in conceptual change does not lie in the change of conceptual structure in individuals’ mind, but rather the change in the situatedness of knowledge (Schnotz, et al., 1999). Multiple representations of a concept may co-exist and the activation of one over another is through the recognition of embedding context (Pozo, et al., 1999). Consequently, conceptual change is achieved when a situation is created “where the appropriate

scientific idea will come into play” (Halldén, 1999, p. 53). Sociocultural researchers pay special attention to tools, signs, and discourses, and argue that learners’ reasoning can be very different with or without the access to tools (e.g., Ivarsson, Schoultz, & Saljo, 2002).

Summary. This section introduces the major perspectives of conceptual change, the factors hindering or contributing to conceptual change, and the instructional implications from different perspectives. As can be seen, salient differences exist between the cognitive and the sociocultural perspectives. While cognitive tradition considers conceptual change as ultimately the acquisition of scientifically correct mental structure, sociocultural perspectives emphasize the participation in communities of practice, the engagement in social discourse, and the utilization of the tools. Sfard’s (1998) “acquisition” versus “participation” metaphor vividly captures the difference (Mason, 2007). Recently researchers called for the bridging of the two different views and advanced different proposals. Some researchers tried to reconcile the two perspectives by suggesting the “acquisition via participation” proposal (e.g., Vosniadou, 2007a), while others believe that the bridging is unachievable because the two views are epistemologically incommensurable (Alexander, 2007; Ivarsson, et al., 2002).

From a pragmatic point of view, I lean toward Vosniadou’s (2007a) “acquisition via participation” proposal. The importance of cognitive functioning has been established by a long history of empirical research. On the other hand, studies have also convincingly shown that learning is not a function of mental activities alone. I recognize that the two perspectives, coming from distinctly different philosophical roots, are indeed epistemologically incommensurable – one emphasizes that learning takes place in individuals’ minds and that knowledge is the acquisition of expert cognitive structure,

while the other conceptualizes learning as a sociocultural activity and knowledge as “getting better at participating in a situated activity” (Greeno, Smith, & Moore, 1993, p. 100). In the mean time I also believe that in educational research and practice much can be done to reconcile the two. Both perspectives can inform the design of instruction to promote conceptual change. Therefore, this study investigated conceptual change by incorporating cognitive, motivational, and sociocultural perspectives. In the context of the current study, conceptual change is defined as a gradual process during which one’s cognition, metacognition, motivation, affect, and sociocultural experiences interact with each other, with the outcome being the radical reconstruction of one’s original cognitive structure. While the “acquisition” of expert cognitive structure is important, the process of “participation” in the intentional, sociocultural learning process is equally important.

Among the factors that may influence conceptual change, of particular interest in this study were two factors: (a) a metacognitive factor – metaconceptual thinking [a subset of metacognition that is related to one’s conceptual understanding (Yuruk, Beeth, & Andersen, 2008)], and (b) a motivational factor – epistemological beliefs [one’s beliefs about the nature of knowledge and knowing (Hofer & Pintrich, 1997)].

Linking back to the criticism of the traditional conceptual change model’s assumption of the learner as scientist, we can see that the two factors being addressed in this study – epistemological beliefs and metaconceptual thinking, are essentially about being more like a scientist – in terms of developing a sophisticated view of what constitutes knowledge and knowing in science and in terms of taking one’s conceptual ecology under close examination. These two aspects are addressed in the next two sections of this chapter.

Epistemological Beliefs

The origin and the unidimensional models. Epistemology is a branch of philosophy that studies the nature of knowledge and knowing (Hofer & Pintrich, 1997). As human beings, we hold implicit beliefs about knowledge and knowing, which are termed as epistemological beliefs or personal epistemology (Hofer & Pintrich, 2002). Empirical studies on epistemological beliefs originated from Perry's (1970) earlier investigations of college students' ethical and intellectual development. In his 15-year longitudinal study, Perry followed a group of male undergraduate students at Harvard University throughout their years in college. The analysis of interviews throughout these students' college years revealed a pattern which was summarized by Perry (Hofer & Pintrich, 1997; Perry, 1970). According to Perry (1970), college students' moral and intellectual development can be characterized by nine positions which were further clustered into four categories: dualism, multiplicity, relativism, and commitment within relativism. Along this continuum, individuals develop from viewing the world as dualist, black or white, and absolute to a more mature view that recognizes multiplicity, understands the world as relative, contingent, contextual and makes a commitment to one's values, responsibilities, and identity within relativism (Hofer & Pintrich, 1997).

Following Perry's pioneering study, more researchers started to take interest in the nature of people's intellectual development. While Perry's study was almost exclusively on male college students, Belenky and colleagues (Belenky, Clinchy, Goldberger, & Tarule, 1986) conducted their phenomenological studies on college-educated female students. Their model, which was named as "women's ways of knowing," suggested five positions that characterize how women perceive knowing:

silence, received knowing, subjective knowing, procedural knowing, and constructed knowing (Buehl & Alexander, 2001).

While both Perry's and Belenky et al's studies were each of a single gender, Baxter-Magolda (1992) followed Perry's study approach but included both female and male samples from a university. The research on both genders yielded findings different from those of Perry's, leading Baxter-Magolda to develop her own Epistemological Reflection Model to explain the ways in which students conceptualize knowledge and learning (Buehl & Alexander, 2001). The model consists of four ways of knowing with increasing maturity: absolute knowing, transitional knowing, independent knowing, and contextual knowing.

King and Kitchener (2004) also studied the epistemological development of both genders, but their study included both high school students and middle-age adults. King and Kitchener's focus was on people's underlying epistemological assumptions when faced with ill-structured, controversial problems. From their interview data, Kitchener and King (1981) proposed the Reflective Judgment Model (RJM). RJM suggests a seven-stage developmental sequence of reflective thinking distinguished by different underlying epistemological assumptions. The seven stages are grouped in three levels: prereflective thinking (Stages 1-3), quasi-reflective thinking (Stages 4-5), and reflective thinking (Stages 6-7) (P. King & Kitchener, 2004). Individuals with prereflective thinking believe that knowledge is certain and therefore there is always one single correct answer for all questions. With quasi-reflective thinking, individuals start to realize the uncertainty and the constructive nature of knowledge and knowing. While recognizing that evidence is important in the process of knowing, individuals at this level are still not competent at

linking evidence to conclusions. Only when individuals reach the third, reflective level can they comfortably navigate between evidence and judgment with reasoning.

Individuals at this level also start to recognize that knowledge is contextual and are open to review and revise their understandings (P. King & Kitchener, 2004). According to King and Kitchener (2004), the fourth stage, which belongs to quasi-reflective thinking, is the stage where the majority of college students are located, while the seventh stage, which is the stage with the highest level of reflective thinking, is the ultimate goal of higher education.

In a similar manner, Kuhn (1991), who was interested in people's everyday reasoning, interviewed individuals of different ages (teens, 20s, 40s, and 60s) to make sense of their reasoning. Her study summarized three epistemological views regarding the certainty of knowledge, ranging from absolutists (who believe knowledge is certain and absolute), multiplists (who admit that there are different but equally equivalent views), to evaluative (who realize that different views can be compared and evaluated).

While the researchers reviewed above took different study interests, used different approaches, and studied different populations, their findings share the same developmental trend. That is, their models all suggest a developmental spectrum along a single dimension, with naïve views on one end and sophisticated views on the other, and the views appear to move to the mature end as individuals grow and gain more educational and life experience.

On the other hand, as some researchers have pointed out (Buehl & Alexander, 2001; Hofer & Pintrich, 1997), the models reviewed above were mainly meant to study people's everyday reasoning rather than learning in an academic setting, and therefore the

subjects' epistemological beliefs and their relationship with learning were not explicitly focused on in these studies. Further, these models all suggest a general, unidimensional progress of epistemological beliefs (Buehl & Alexander, 2001; Schommer, 1990), ranging from viewing knowledge and knowing as dualistic, absolutist and objectivist on one end to "relativist, subjectivist, contextual, constructivist, and evaluative" on the other (Stathopoulou & Vosniadou, 2007, p. 146). Starting from the 1990s, Schommer and other researchers explored new conceptions of epistemological beliefs, which are reviewed next.

The multi-dimensional model of epistemological beliefs. In reflecting on the mixed study results based on Perry's developmental model and asking how epistemological beliefs impact student learning (particularly comprehension), Schommer (1990) questioned the unidimensional conception of epistemological beliefs, suggesting that epistemological beliefs may be a system consisting of several independent dimensions. Therefore Schommer proposed five dimensions of the epistemological belief system, and developed a self-report quantitative survey – Schommer Epistemological Questionnaire (SEQ) to test her model. Factor analysis yielded four factors: innate ability, simple knowledge, quick learning, and certain knowledge.

While proposing still another developmental model of epistemological beliefs, Schommer changed the landscape of epistemological belief research in several ways. First, in contrast with the traditional unidimensional conception of epistemological beliefs, Schommer (1990) suggested the possible multidimensionality of this construct. Second, the SEQ, a quantitative self-report survey instrument, made it possible to quantitatively study epistemological beliefs on a large scale. Thirdly, because of the

availability of the quantitative survey instrument, researchers were able to examine the link between epistemological beliefs and various aspects of learning. Following Schommer's lead, researchers began to develop more self-report survey instruments trying to capture the multidimensionality of epistemological beliefs and use the instruments to study the relationships between epistemological beliefs and a variety of cognitive, affective, and motivational factors involved in student learning. The section below briefly reviews these research findings.

Epistemological beliefs and learning. Generally speaking, advanced epistemological beliefs appear to link to positive learning outcomes. For example, Schommer and colleagues have conducted several studies examining epistemological beliefs and text comprehension. In one study, Schommer (1990) asked students to read a passage on either social science or physical science with the last paragraph removed. Students were asked to rate their confidence in understanding the passage, write the concluding paragraph, and complete a mastery test. Results showed that student beliefs in quick learning were linked to oversimplified conclusions and poor performance in the mastery test. In addition, beliefs in certain knowledge were shown to predict inappropriately absolute conclusions in the concluding paragraphs written by students. In another study focusing on the belief in simple knowledge and its effects on mathematical text comprehension, Schommer, Crouse, and Rhodes (1992) found similar results, that beliefs in simple knowledge resulted in poor test performance and inaccurate estimate of one's actual understanding. In addition to text comprehension, studies have also found influence of beliefs in quick/fixed learning on middle school students' math problem solving (Schommer-Aikins, Duell, & Hutter, 2005) as well as the effects of beliefs in the

speed of learning on college business students' academic performance (Schommer-Aikins & Easter, 2006). Also, beliefs in gradual learning and incremental ability positively impacted middle and high school students' GPA (Schommer-Aikins, et al., 2005; Schommer-Aikins, Mau, Brookhart, & Hutter, 2000; Schommer, 1993).

While the studies reviewed up to this point suggest that advanced epistemological beliefs are generally associated with better academic performance, a recent study by Norwegian researchers Bråten, Strømsø, and Samuelstuen (2008) had some unexpected findings. In their study, Norwegian undergraduate students were assessed on their topic-specific epistemological beliefs about climate change before reading multiple texts on climate change. The unexpected findings were that those students who viewed the source of the knowledge about climate change as their personal construction performed poorer when compared with those who viewed experts as source of the knowledge. While more studies are needed to replicate the findings, this study suggested that, advanced epistemological beliefs in certain dimensions are not always linked to positive learning outcomes.

In addition to direct impact on academic performance, epistemological beliefs were also found to affect students' cognitive engagement and study strategies. Ravindran, Greene, and DeBacker (2005) examined the relationship between epistemological beliefs and preservice teachers' cognitive engagement. The findings revealed that individuals with naïve epistemological beliefs tended to show shallow cognitive engagement whereas those with more advanced beliefs showed more meaningful engagement. Similar results were also reported by DeBacker and Crowson (2006), who found significant correlations between naïve epistemological beliefs and shallow cognitive engagement.

In their study on epistemological beliefs and mathematics text comprehension, Schommer et al. (1992) found a significant relationship between college students' belief in simple knowledge and test-preparation strategies. In another study examining epistemological beliefs and undergraduate students' cognitive strategies in reading a dual-positional text on HIV-AIDS relationship, Kardash and Howell (2000) found that the beliefs in the speed of learning affected the cognitive strategies the students employed while reading the text. In another study, Ryan (1984) asked undergraduate students to describe the criteria they used to evaluate whether or not they understood textbook chapters. The students' reported criteria were subsequently divided into two general categories based on Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956): knowledge and comprehension/application. Students' epistemological beliefs were classified by Perry's scheme of dualist or relativist. The findings suggested that dualists often used criteria that belong to the "knowledge" category, whereas those relativists tended to employ "comprehension/application" criteria to monitor their understanding. Thus, students' epistemological beliefs affect how they perceive their comprehension level while learning from a textbook.

In addition to the influence on academic performance, cognitive engagement and study strategies, epistemological beliefs were also found to affect student motivation. Several studies investigated epistemological beliefs and achievement goals. DeBacker and Crowson (2006) treated epistemological beliefs as a single index in their study and found that students' overall epistemological beliefs predicted all three achievement goals, with those who held more naïve beliefs being less likely to adopt mastery goals but more likely to adopt performance approach or avoidance goals. Bråten and Strømsø's (2004)

study linked specific dimensions of epistemological beliefs to achievement goals. The findings suggested that Norwegian college students who believed in quick learning were less likely to adopt mastery goals, but instead would adopt performance approach or avoidance goals. In addition, those who believe that knowledge is stable and given were less likely to adopt mastery goals. Different from the above two studies, Ravindran and colleagues (2005) found that none of the dimensions of epistemological beliefs was correlated with learning goals, whereas two belief dimensions (innate ability and simple learning) were correlated with performance goals. Buehl and Alexander (2005) examined the relationship between students' epistemological beliefs and their competency beliefs and achievement value. It was found that, in both history and mathematics domains, students with more sophisticated epistemological beliefs demonstrated more motivation than those with more naïve beliefs.

In summary, epistemological beliefs are related to academic performance, cognitive engagement, and study strategies, as well as student motivation. Generally speaking, the literature suggests that those who hold more sophisticated beliefs tend to show better learning outcomes, utilize more effective study strategies, engage in more meaningful learning, and exhibit higher motivation.

While earlier studies on epistemological beliefs assumed that the beliefs do not vary across different knowledge domains, in recent years researchers started to question such domain-general assumptions by suggesting that the same individual's epistemological beliefs may vary across different knowledge domains or even different topics. The next section reviews the domain-specific claims about epistemological beliefs.

Domain-general and domain-specific claims. Questioning whether epistemological beliefs were general across different domains, Schommer and Walker (1995) set out to explore the differences in college students' epistemological beliefs between the domains of social sciences and mathematics. Their findings suggested that epistemological beliefs are mainly domain-general, while the smallest correlations between the two domains occurred in the belief of certain knowledge.

Schommer and Walker's (1995) study measured students' domain-specific beliefs with a domain-general epistemological belief questionnaire while asking students to think about a particular domain while completing the questionnaire. Such an approach was questioned by other researchers. As a result, Hofer (2000) developed a new instrument intended to measure domain-specific beliefs and used the instrument to investigate domain-specificity of epistemological beliefs. Hofer's (2000) findings suggested that there are underlying general beliefs that transcend domains, while there are also differing beliefs across domains. Similar findings were later obtained by Buehl and Alexander (2002) who also used a domain-specific instrument to probe and compare students' beliefs in mathematics and history. In reviewing studies on the beliefs among people of different majors as well as the same individuals' beliefs about different domains, Buehl and Alexander (2001) proposed a multi-layered model of epistemological beliefs, consisting of a fundamental domain-general layer and also a domain-specific layer. To provide more evidence for their model, Buehl and Alexander (2005) used cluster analysis to examine students' epistemological belief profiles in the domains of mathematics and history. The analysis suggested that while students have different belief profiles in the two domains, the level of sophistication in their beliefs was found to be relatively

consistent between the two domains. Thus again the findings support the dual nature of epistemological beliefs.

More recently Muis, Bendixen, and Haerle (2006) reviewed 19 empirical studies that investigated the domain-specificity of epistemological beliefs and found evidence of both similarities and differences across domains. The researchers posited that as one progresses in education, their domain-general beliefs become less dominant whereas domain-specific beliefs grow in impact. In another effort to compare general and domain-specific epistemological beliefs, Kienhues, Bromme, and Stahl (2008) suggested that while general beliefs may be more stable over time, domain-specific beliefs may be more malleable to instructional interventions. The next section discusses the malleability of domain-specific epistemological beliefs.

Malleability of epistemological belief. Epistemological belief has traditionally been conceptualized and studied as a trait-like construct that exerts influence on different aspects of learning. As research studies revealed the important role of epistemological beliefs in learning, it became natural to ask whether it is possible to improve epistemological beliefs through instructional interventions. Therefore, in recent years research has been conducted to investigate the development of epistemological beliefs as a learning outcome.

Several studies have been conducted in the domain of mathematics. Gill, Ashton, and Algina (2004) found that after a short instructional intervention with refutational text, preservice teachers made significant changes toward more sophisticated math-specific beliefs compared with their counterparts in a control group, as demonstrated in measures on both explicit and implicit beliefs. In her synthesis paper, Muis (2004) reviewed six

studies aimed at changing learners' epistemological beliefs in mathematics through constructivist-oriented teaching approaches. Overall, positive results were found across the reviewed studies.

In the domain of science, inquiry-based activities are often used to promote students' science-specific epistemological beliefs. Carey and colleagues (Carey, Evans, Honda, Jay, & Unger, 1989) used a three-week unit to promote students' epistemological beliefs in science by engaging them in hypothesis testing, theory building and reflective activities. Scorings on pre- and post-instruction clinical interviews revealed significant improvement in the students' epistemological beliefs in science. Smith, Maclin, Houghton, and Hennessey (2000) compared two groups of sixth-graders who went through the elementary science curriculum that reflected either constructivist or traditional instructional approaches. Clinical interviews suggested that the group that went through the constructivist-oriented curriculum demonstrated more sophisticated science epistemological beliefs than did the other group. In another study conducted by Conley, Pintrich, Vekiri and Harrison (2004), elementary students' science epistemological beliefs were measured by a self-report survey along four dimensions: *Certainty*, *Source*, *Development*, and *Justification*. After completing a nine-week science unit featuring hands-on activities, the students showed significant improvement in the *Certainty* and *Source* dimensions of science epistemological beliefs, whereas no improvement was found in the *Development* and *Justification* dimensions. In another study in which the experimental group of students collaborated in knowledge building activities (pose question, generate hypothesis, construct explanations, and revise theory),

the students demonstrated more gains in epistemological beliefs when compared with the control group that received traditional instruction (Lam & Chan, 2008).

In addition to inquiry-based activities, other ways have also been experimented with to promote students' epistemological beliefs. Valanides and Angeli (2005) taught undergraduate students critical thinking principles to promote their epistemological development. Among three treatment groups, the researchers found that the group in which students had opportunity to reflect, debate, and evaluate their own thinking over an ill-defined and controversial issue made significant changes in epistemological beliefs when compared with the other two groups.

Borrowing strategies from conceptual change, Kienhues et al. (2008) directly confronted and challenged students' naïve epistemological beliefs with refutational text. It was found that the refutational text worked well for students holding naïve beliefs, but for those who already had more sophisticated beliefs, the refutational text seemed to lead them toward the naïve end of the belief, which was somewhat unexpected.

To summarize, it appears that through appropriate instructional interventions, it is possible to improve students' domain-specific epistemological beliefs. Among the different strategies, inquiry-based activities are most frequently used. In addition, engaging students in critical thinking activities over ill-structured, controversial issues also has potential to improve students' epistemological beliefs. Finally, while more studies are needed to replicate the findings, it seems that directly refuting naïve epistemological beliefs through refutational text works best for those who hold naïve beliefs while having negative effects on those whose beliefs are more advanced.

Measurement of epistemological beliefs. In the early days of epistemological belief research, the construct was often measured qualitatively through clinical interviews or open-ended questionnaires. Following the lead of pioneer researchers (e.g., Kitchener & King, 1981; Perry, 1970), a clinical interview was once the dominant approach to probing one's beliefs in knowledge and knowing. The purpose of the interview was to understand how age and education led to the development in individuals' epistemological beliefs. The results from the interviews generally positioned an individual at a particular level along a developmental dimension of epistemological beliefs, that is, from the naïve to the sophisticated end along a continuum. Later, based on the theories developed from clinical interviews, open-ended questionnaires were designed to probe students' epistemological beliefs (Baxter-Magolda, 1992).

While clinical interviews and open-ended questionnaires provide rich information about individuals' epistemological beliefs, data collection and analysis is a costly and time-consuming process, and consequently this limited the sample size a research study can handle. The Schommer Epistemological Questionnaire (SEQ) (Schommer, 1990), a self-report Likert-type scale, marked the beginning of large-scale, quantitative measurement of epistemological beliefs. However, the instrument itself has received criticisms for its unstable factor structures across studies (e.g., DeBacker, Crowson, Beesley, Thomas, & Hestevold, 2008) and for the inclusions of certain dimensions that are not considered as epistemic in nature (e.g., Hofer, 2000). Trying to address the problems identified with the SEQ, several other quantitative measures have been developed. The Epistemic Beliefs Inventory (EBI) (Schraw, Bendixen, & Dunkle, 2002) and the Epistemological Belief Survey (EBS) (Wood & Kardash, 2002) are two examples.

While each of the two has its own psychometric problems, they were found to be better than SEQ in measuring general epistemological beliefs, and particularly EBS appears to have fewer issues than the other two (DeBacker, et al., 2008). Therefore, in this study EBS was used to measure students' general epistemological beliefs.

In the particular domain of science, Carey and colleagues (1989) were among the first to devise a clinical interview to probe students' "views on the nature of science knowledge and inquiry" (p.516). Referring to Kuhn and colleagues' (D. Kuhn, Amsel, & O'Loughlin, 1988) research on students' development of scientific thinking skills, the interview asks students a series of questions to tap their views of the nature of science in four particular clusters: the goal of science, the questions asked in science, the nature and purpose of science experiments, and the nature of the change processes (Carey, et al., 1989; Smith, et al., 2000). Later researchers in science education devised open-ended questionnaires to be used in conjunction with clinical interviews to assess students' views of the nature of science (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Coming from another line of research in science education, these instruments on the views of the nature of science (VNOS) probe not only students' science-specific epistemological beliefs but also other dimensions such as the history and sociology of science. Nonetheless, science epistemological beliefs do constitute part of this type of instrument to certain degree.

Parallel to the development of quantitative self-report instruments to measure domain-general epistemic beliefs, effort has been made to develop quantitative measures to probe domain-specific beliefs. In the domain of science, for example, Hofer (2000) developed an instrument that attempted to tap the four dimensions of beliefs (simple

knowledge, certain knowledge, source of knowing, and justification of knowing) in the domain of science. To understand fifth graders' epistemological beliefs in science, Elder (2002) developed a questionnaire with four factors: *Source*, *Certainty*, *Development*, and *Justification*. The questionnaire was later adapted by Conley et al. (2004). In both studies, the instruments were developed for elementary students; therefore the items are appropriate for the research participants of the current study who are middle school students. Further, the instrument was used in Conley et al.'s (2004) study to measure changes in elementary students' science epistemological beliefs after science inquiry activities. Given the similarities in research participants and research purpose, this instrument serves well for the current study.

Summary. Epistemological beliefs, the beliefs individuals hold about the nature of knowledge and knowing (Hofer & Pintrich, 1997), have traditionally been studied as a single-dimensional, domain-general construct. In recent years, studies have found that epistemological beliefs are multi-dimensional (Schommer, 1990). Moreover, it is now generally recognized that, while there is an underlying layer of domain-general beliefs, individuals also hold different beliefs in different knowledge domains (Buehl & Alexander, 2002). Because epistemological beliefs may exert influence on learning, it becomes desirable that instructional interventions help to advance learners' epistemological development. There are some beginning discussions suggesting that while domain-general beliefs tend to be more stable, domain-specific beliefs may be more susceptible to instructional interventions (Kienhues, et al., 2008). In the domain of science, effort has been made to develop students' science epistemological beliefs

through strategies like inquiry learning and reflective discourse, and the results appear to be encouraging (e.g., Smith, et al., 2000).

Based on the reviewed literature, the construct of epistemological belief plays a double role in this study. On one hand, students' domain-general epistemological beliefs are examined in terms of their possible effects on conceptual change learning outcomes; on the other hand, the study also takes an interest in investigating the effects of possible instructional interventions on the development of learners' science epistemological beliefs. Regarding the instruments to measure domain-general and science-specific epistemological beliefs, Wood and Kardash's (2002) EBS and Conley et al.'s (2004) science epistemological belief survey were adapted respectively in order to quantitatively study the constructs and their relationships with other variables in this study.

The remainder of this part of literature review discusses another important construct in this study, namely metaconceptual thinking.

Metaconceptual Thinking

Metaconceptual thinking belongs to a broader category of metacognition. According to Yuruk et al. (2008), the term "metaconceptual" refers to "metacognitive knowledge and processes that are acting on and related to one's conceptual system" (p.444). Before proceeding to the metaconceptual level, it is helpful to have a brief review of metacognition and its role in learning, in order to set the stage for the discussion of metaconceptual thinking.

Metacognition. Metacognition has its roots back in the developmental research in the 1970s. In his pioneering work, Flavell (1976) identified metacognition as something

that young children lack in learning. He referred to this as “the active monitoring and consequent regulation and orchestration of [one’s cognitive processes]” (p.232).

Since the inception of research on metacognition, researchers have proposed different taxonomies trying to make sense of metacognition. Among them, A. L. Brown (1978) defined metacognition as the knowledge and regulation of cognition, thereby classifying metacognition into two major components: the knowledge about cognition, and the regulation and monitoring of cognition. Pintrich, Wolters, and Baxter (2000) went further to separate the monitoring and the regulation of cognition, thus proposing three components of metacognition: metacognitive knowledge, metacognitive judgment and monitoring, and self-regulation and control of cognition.

Often described as “thinking about one’s own thinking,” metacognition has been found to be positively related to academic performance such as reading comprehension, problem solving, and transfer of learning (Boulware-Gooden, Carreker, Thornhill, & Joshi, 2007; Lin & Lehman, 1999; Schoenfeld, 1991; Swanson, 1990).

Realizing the values of metacognition in learning, researchers have tried to devise strategies to promote metacognition. It was encouraging to find that metacognition is trainable through appropriate instructional strategies (Hodge, Palmer, & Scott, 1992; Nietfeld & Schraw, 2002). Reciprocal teaching (Palincsar & Brown, 1984) and metacognitive prompting (Scardamalia, Bereiter, & Steinbach, 1984), for example, are among the strategies used to promote metacognition.

Metaconceptual thinking. In the context of conceptual change, the term “metaconceptual awareness” has been used to describe metacognitive thinking at the level of *conceptual* knowledge and learning. Murphy and Mason (2006) implied more

broadly that metaconceptual awareness is one's thinking *about* their conceptions instead of thinking *with* the conceptions. At a more specific level, Vosniadou et al. (Vosniadou, et al., 2001) referred to metaconceptual awareness as learners' awareness of (a) the presuppositions and beliefs that constrain their learning, (b) the hypothetical nature of their presuppositions which allows questioning and verification or falsification of these presuppositions (Vosniadou, et al., 2001), (c) the differences between naïve beliefs and scientific concepts (Mikkila-Erdmann, 2001; Vosniadou, 2007b), (d) the changes in one's conceptual understanding (Mason & Boscolo, 2000). In addition, Wiser and Amin (2001) used the term metaconceptual understanding to refer to one's understanding that scientists and lay persons may use the same term to refer to different things (e.g., heat as exchanged energy vs. heat as hotness). Further, in her effort to use analogy to promote conceptual change, Mason (1994a, 1994b) described metaconceptual awareness as learners' understanding about the function and purpose of analogy.

As illustrated, while there appears to be a general agreement that metaconceptual thinking is a subset of metacognition and it refers to the thinking *about* one's conceptions, there are inconsistencies among researchers in the terms used and the meanings attached to the terms. Different researchers emphasize different aspects of this construct. In this study, *metaconceptual thinking* is used as an encompassing term that incorporates the various terms used in the past (e.g., metaconceptual awareness, metaconceptual understanding). To better understand its impact on conceptual change and to guide metaconceptual intervention aiming at promoting conceptual change, it is necessary to clarify the meaning of metaconceptual thinking and to distinguish it from a broader

category of metacognition (Thorley, 1990). It was in this context that Yuruk et al. (2008) made the first attempt to clarify metaconceptual thinking.

Yuruk et al. (2008) described metaconceptual thinking as “metacognitive knowledge and processes that are acting on and related to one’s conceptual system,” thus “metaconceptual” does not include “higher order thinking knowledge and processes about cognition in general” (p.452). Drawing from different taxonomies of metacognition, Yuruk et al. (2008) presented a systematic framework to characterize metaconceptual thinking, which constitutes metaconceptual knowledge and three metaconceptual processes: (a) metaconceptual awareness, (b) metaconceptual monitoring, and (c) metaconceptual evaluation. According to Yuruk et al. (2008), metaconceptual knowledge is the “stable and storable knowledge about concept learning and the factors influencing concept formation” (p.453). Metaconceptual awareness is “one’s awareness of and reflection on existing and past concepts and elements of conceptual ecology” (p.453). Metaconceptual monitoring is an “online process” (p.453) that monitors one’s conceptual understanding and thinking process. Lastly, metaconceptual evaluation refers to the learners’ judgment of the competitive conception. In investigating their metaconceptual intervention to promote students’ conceptual understanding, Yuruk et al. (2008) found evidence for all the three metaconceptual processes.

With a clear definition of metaconceptual thinking and a systematic framework, it is possible to target specific metaconceptual knowledge and processes in designing instructional interventions.

Metaconceptual intervention. Ever since researchers discovered the importance of metacognition in conceptual change, instructional interventions have been conducted

with the goal of promoting learners' metacognitive thinking. While "metaconceptual" is not always explicitly stated, a significant part of the interventions in these studies were trying to promote learners' metaconceptual thinking.

Classroom discussion is a frequently used strategy. In Eryilmaz's (2002) approach to conceptual change, students were engaged in guided discussions to expose their conceptions, make their own hypotheses explicit, confront different conceptions held by others, and become aware of the possible cognitive conflicts they were facing. Similarly, Mason (2001) engaged students in large and small groups to share their initial conceptions with others, formulate hypotheses, and discuss findings from experiments.

In another intervention, an expert teacher utilized a set of seven learning goals to guide discussions in science classrooms (Beeth, 1998b). The following seven goals were presented at the beginning of the semester and emphasized throughout the process, which encouraged students' metaconceptual thinking.

1. Can you state your own ideas?
2. Can you talk about why you are attracted to your ideas?
3. Are your ideas consistent?
4. Do you realize the limitations of your ideas and the possibility they might need to change?
5. Can you try to explain your ideas using physical models?
6. Can you explain the difference between understanding an idea and believing in an idea?
7. Can you apply intelligible and plausible to your own ideas? (p.1093)

The same expert teacher employed another intervention, in which the status of one's conceptual understanding as intelligible (understandable) or plausible (believable) was used as a metacognitive tool to engage students in metaconceptual thinking (Beeth, 1998a). Specifically, students first worked together with the teacher to define the meaning of "intelligibility" and "plausibility" as the status of one's conceptual

understanding, and then applied the constructs to elaborate their ideas and discuss with others throughout the learning process. The students' use of the status language not only stimulated their conscious examination of the development of their ideas and provided them with a means to describe their understanding, but also opened a window through which the instructor could detect and remediate student learning difficulties. While no conceptual change learning outcomes were reported in either of the studies (Beeth, 1998a, 1998b), students were observed actively engaging in metaconceptual thinking.

In addition to discussion, writing is another often used metaconceptual intervention. In Mason and Boscolo's (2000) study, students wrote to comment on others' ideas, reason and reflect on their own ideas, express doubts, and synthesize what they had learned. These students demonstrated better conceptual change than the control group students. White and Gunstone (1989) implemented the PEEL (Project for Enhancing Effective Learning), a longitudinal effort intended to promote "metalearning" in a secondary school in Australia. Students wrote diaries to answer prompting questions like "What is the topic? What do I know about it? How does the new knowledge compare with what I used to think?"

The questioning strategy used in PEEL pertains to a line of research on scaffolding (Vygotsky, 1978), particularly question prompting (Ge & Land, 2004; A. King, 1991; Scardamalia, et al., 1984). By posing questions for students to consider and respond, question prompting strategy was found effective in facilitating problem solving in both well-structured and ill-structured tasks (Ge & Land, 2003; A. King & Rosenshine, 1993; Lin & Lehman, 1999). Cognitively, question prompts guide the problem solver through the stages of problem representation, solution development, and argumentation

construction. Metacognitively, question prompts facilitate the learner to monitor and evaluate solutions throughout the problem solving processes (Ge & Land, 2004). While question prompting has been widely used as a scaffolding strategy to support problem solving, there has been little research on the effects of question prompts on facilitating metaconceptual thinking for the purpose of conceptual change. On the other hand, question prompts have been used in science education to promote students' metacognition, which led to positive findings (e.g., Davis & Linn, 2000; Lin & Lehman, 1999). Considering that metaconceptual thinking is a subset of metacognition, and that question prompting has been successful in promoting metacognition in problem solving and science learning (Ge & Land, 2003; Rosenshine, Meister, & Chapman, 1996), we have reason to believe that question prompting can be a promising strategy to promote metaconceptual thinking.

Instead of using a single approach to encourage metaconceptual thinking, some instructional interventions employed multiple approaches. Hennessey (2003) described META (Metacognitive Enhancing Teaching Activities), a longitudinal project in which elementary students engaged in discussions with the instructor and fellow students, verbal or written self-reflections, and activities like concept mapping, model building, and poster production which were intended for students to make explicit their preconceptions and the development of ideas. Similarly, Yuruk et al (2008) utilized a variety of activities to engage learners in metaconceptual discourse: poster drawing, writing, debate, concept mapping, and discussions. Evidence showed that the students demonstrated metaconceptual thinking while engaging in these activities.

As can be seen, the reviewed metaconceptual intervention was implemented in various forms. In essence, these approaches were intended to facilitate learners' metaconceptual processes, which were summarized nicely by Yuruk et al. (2008):

- (a) reflect on their existing conceptions, the associated ontological presuppositions, past experiences, and contexts in which concepts are used;
- (b) make reference to their past ideas; (c) monitor their understanding of the new conception, other people's ideas, the consistency between existing ideas and information coming from other sources and the change in ideas; and (d) evaluate the relative ability of competing conceptions to explain a physical phenomenon (p.458).

While the interventions reviewed above mainly emphasize metaconceptual processes, another aspect in Yuruk et al.'s (2008) taxonomy, metaconceptual knowledge, is also important in instructional interventions. Examples of metaconceptual knowledge include understanding the difference between science language and everyday language (Wiser & Amin, 2002), the purpose of cognitive tools such as analogy to aid conceptual learning (Mason, 1994a), the difference between understanding and believing (Beeth, 1998a), and the importance of examining one's existing idea (Yuruk, et al., 2008). These are all metaconceptual knowledge that, once equipped, can contribute to conceptual learning.

Linking Together: Examining the Relationships

After establishing a general understanding of the major constructs in this study, this part of the literature review focuses on the specific relationships among the reviewed constructs (see Figure 1 for an illustration of the relationships). Empirical evidences are presented and knowledge gaps are identified, which sets the stage for the research questions.

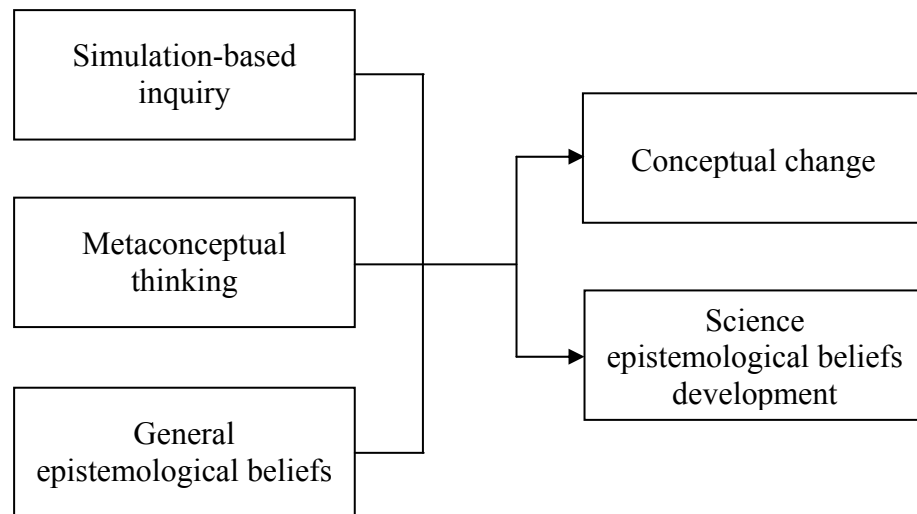


Figure 1. Relationships among the major constructs in the study

Epistemological Beliefs and Conceptual Change

While plenty of studies have investigated the link between epistemological beliefs and various aspects of learning, few have focused on the connections between epistemological beliefs and conceptual change. Qian and Alvermann (1995) were among the first to examine the relationship between learners' general epistemological beliefs and conceptual change learning outcomes. Two hundred twelve 9th-12th grade students completed Schommer's SEQ and a prior knowledge test. The fifty three items from the SEQ loaded on three factors: simple-certain knowledge, quick learning, and innate ability. The prior knowledge test was intended to measure students' existing knowledge of Newton's laws of motion. The test consisted of 10 true-false items that measured commonly held misconceptions about projectile motion, and two application problems that asked students to predict paths of cannon shots. Students then took 15 minutes to read a refutational text that directly confronted common misconceptions about Newton's first law of motion. Afterwards, the students took an achievement test that evaluated their conceptual understanding and knowledge application. Canonical correlation found that

the students' epistemological beliefs were moderately associated with their conceptual understanding and knowledge application. Further, beliefs about simple-certain knowledge and quick learning were two significant predictors of conceptual change learning outcomes.

In Windschitl's (1997) study, 255 undergraduate biology students spent three hours in dyads to study photosynthetic and respiratory processes in plants by using a computer simulation. Conceptual change learning outcomes were measured with 14 conceptual questions. SEQ was adapted to measure one dimension of epistemological beliefs: belief in the complexity of knowledge acquisition. Regression of learners' pretest and epistemological beliefs on their posttest score revealed that the learners' beliefs in the complexity of knowledge acquisition were a significant predictor of posttest scores.

In another study by Windschitl and Andre (1998), 250 non-biology undergraduate students learned human circulatory systems using a computer simulation and accompanying simulation guide. Learning outcomes were measured with a 24-item multiple-choice test. Epistemological beliefs were measured using the SEQ, while all the dimensions were added as one composite variable. Among other findings from this study, regression analysis showed that the students' epistemological beliefs significantly predicted their posttest scores.

To summarize the connections between epistemological beliefs and conceptual change, it appears that certain dimensions (e.g., simple and certain knowledge) of epistemological beliefs may contribute to conceptual change learning outcomes. Given that few studies investigated the link between epistemological beliefs and conceptual change in science, and existing studies either treated multiple dimensions of

epistemological beliefs as a single variable (e.g., Windschitl & Andre, 1998) or only measured certain dimensions of epistemological beliefs (e.g., Windschitl, 1997), it is not exactly clear which dimensions may significantly contribute to conceptual change, particularly in the context of simulation-based science inquiry. More studies are needed to clarify the relationship.

Metaconceptual Thinking and Conceptual Change

As reviewed earlier, unlike scientists who consciously and continuously put their own ideas under investigation, students often are not aware of the metaconceptual knowledge associated with conceptual learning, nor are they actively engaged in metaconceptual monitoring and evaluation processes. Intuitively, metaconceptual thinking should contribute to conceptual change. This was pointed out by several researchers who recognized the important role of metaconceptual thinking in conceptual change (e.g., Hennessey, 2003; Vosniadou, et al., 2001). Mason's (1994a) study provided some empirical evidence for such claims. In her intervention, using analogy to promote conceptual change, Mason found that students' metaconceptual awareness of the purpose and use of analogy to change their initial conceptions was positively correlated with their conceptual understanding.

Since the concept of metaconceptual thinking has not been clearly defined until very recently (Yuruk, et al., 2008), few studies explicitly implemented metaconceptual intervention and examined its effectiveness. Often metaconceptual thinking is implicitly addressed as part of broader-scope interventions aiming at conceptual change. For example, in Vosniadou and Kollias' (2003) study, students were engaged in model building activities using a computer-based collaborative learning system to support their

critical discourse. Positive effects were found as the critical discourse promoted students' metacognitive skills and intentional learning. In another study, Ravenscroft (2007) designed and used digital dialogue games that modeled reasoning, conceptual change and argumentative processes, and found that improved test performance was associated with the use of the dialogue tools. Takagaki and Tahara (2005) found in their study that when students were engaged in reciprocal teaching, strategies of predicting, theorizing, summarizing, and coordinating the prediction and theories to results this helped to guide student thinking and facilitated conceptual change. Hennessy (2003) reported several exploratory projects aimed at promoting students' metacognition, including the META project introduced earlier, that utilized a variety of strategies to promote conceptual change. While these studies did yield positive conceptual change learning outcomes, they do not point directly to the effectiveness of metaconceptual intervention because the interventions in these studies usually addressed a variety of factors simultaneously, with metaconceptual thinking being only one of the factors.

A few studies have implemented and investigated mainly metaconceptual intervention to promote conceptual change. For example, in Bieman and Simons' (1995) study, students read instructional text and answered questions which were designed to emphasize metaconceptual thinking in five steps: (a) before studying a text, searching for own preconceptions; (b) after reading a text, comparing and contrasting these preconceptions with the new information; (c) formulating new conceptions, based on the previous step; (d) applying the new conceptions; and (e) evaluating the new conceptions, based on the previous step. The participants were assigned to different groups with some groups following all five steps while others only certain part of the steps (e.g., steps *a* and

b only). The quality of students' final conception was measured by answering problem-solving questions that required the utilization of the concepts addressed in the instruction. It was found that the group that went through all the five steps was superior than other treatment groups, suggesting that continuous metaconceptual thinking led to optimal learning outcomes.

Mason and Boscolo (2000) used writing to promote metaconceptual thinking among elementary students. When they were learning photosynthesis, the experimental group students took notes to make comments, reflect on ideas, express doubts, and synthesize information. Learning outcome was measured by open-ended conceptual and transfer questions that were scored based on correctness and completeness. In addition, the students were asked five post-instruction questions to evaluate their metaconceptual awareness, (a) "Do you think your ideas on plant food have changed?" (b) If so, "What were your initial ideas?" (c) "Why did you have those ideas?" (d) "What are your current ideas?" (e) "Has changing your previous ideas been easy or difficult and what made it easy or difficult for you." Comparison with the control group suggested that the experimental group showed better test performance and increased metaconceptual awareness.

In Eryilmaz's (2002) study, discussion was used as a means to promote metaconceptual thinking. High school students were divided into different treatment groups to study force and motion concepts. Students who participated in class discussions that emphasized metaconceptual thinking showed superior performance in both conceptual test and achievement test compared with all the other treatment groups.

Compared with the above studies, Wiser and Amin's (2001) intervention addressed only one aspect of metaconceptual thinking, that the same concept can have different scientific and everyday meanings. Wiser and Amin provided a qualitative account of how the metaconceptual teaching capitalized on what the students had learned previously from direct instruction and other learning activities.

Georghiades (2000) explored a variety of ways to enhance student metacognition in elementary science classrooms. At certain points in his instructional sequence, he implemented activities of two to three minutes' length, during which students engaged in questioning and discussion (e.g., discuss one's conception before instruction, and describe whether and how it was changed), diary keeping (e.g., summarize what has been learned and what remains unclear), annotated drawing to illustrate certain concepts, or concept mapping. Preliminary data analysis found that the treatment group performed better than the control group in the immediate test and delayed posttests conducted two and eight months later. Similarly, Yuruk et al. (2008) implemented multiple strategies to enhance high school students' metaconceptual thinking while learning force and motion topics. The treatment group showed superior performance in the posttest and delayed conceptual tests.

To summarize, while few studies explicitly implemented and examined metaconceptual intervention, existing ones show positive effects. This suggests that interventions aiming at promoting metaconceptual thinking are likely to lead to improved conceptual change learning outcomes. Strategies like discussion, writing, question prompting, and concept mapping appear to be possible means to implement metaconceptual intervention. Given the few existing empirical studies of metaconceptual

intervention, many of which employed qualitative research methodology, and given the lack of a theoretical framework for metaconceptual thinking until very recently, a quantitative study that systematically implements metaconceptual intervention and explicitly investigates its effectiveness would be a valuable addition to the understanding of metaconceptual intervention and its effects on conceptual change.

Epistemological Beliefs and Metaconceptual Thinking

Thus far, the review examines epistemological beliefs and metaconceptual thinking separately. In elaborating her model of personal epistemology, Hofer (2004) postulated that personal epistemology is “a set of beliefs, organized into theories, operating at the metacognitive level” (p.46). If epistemological beliefs operate at the metacognitive level, then would it be possible that epistemological beliefs and metaconceptual thinking are related to each other? Existing literature has provided some clue about this question.

Stathopoulou and Vosniadou (2007) speculated that epistemological beliefs not only directly influence conceptual change, but also indirectly through metacognition. In their case study, the researchers interviewed ten high school students who were selected based on their scores on a conceptual test on force and motion and an epistemological belief survey. Five of the students represented higher achievers with more constructivist epistemological beliefs, whereas the other five represented lower achievers with more objectivist beliefs. Preliminary analysis from the interviews with the students showed that the higher achieving students with more constructivist beliefs were more metaconceptually aware of the development and changes in their conceptual understanding whereas the lower achieving students with more objectivist beliefs were

not metaconceptually aware of the evolution of their conceptual understanding. While no definite conclusion could be drawn from this study, it does indicate the possible interactions between epistemological beliefs and metaconceptual thinking.

Fulton and Kendeou's (2009) study indicated more evidence about the possible connections between epistemological beliefs and metaconceptual thinking. Their study was to examine the effects of epistemological beliefs (advanced vs. naïve) and text structure (refutation vs. non-refutation) on undergraduate students' cognitive processes while reading an instructional text on force and motion. Students' cognitive processes were captured by asking them to think aloud while reading the text, and their think-aloud responses were subsequently coded into eight categories. One of the categories was related to metaconceptual thinking. Statistical analysis found that among those students who read refutational texts, those with more advanced epistemological beliefs were more engaged in metaconceptual thinking than their epistemologically less advanced counterparts, while such difference did not exist among those students who read non-refutational text. The findings suggested that learners with different levels of epistemological beliefs may demonstrate different metaconceptual thinking patterns in different instructional interventions.

As Mason (2002) reasoned, epistemological beliefs work like a "thinking disposition" (p.321). In the above two cases, the evidence seems to point out the possibility that epistemologically more mature learners may be more prone to metaconceptual thinking. If this is the case, then would individuals with more advanced epistemological beliefs benefit more from structured metaconceptual intervention? To the author's knowledge this question has not been explored.

On the other hand, would learners' continuous engagement in metaconceptual thinking play a role in their epistemological development? In their integrative model of personal epistemology, Bendixen and Rule (2004) described metacognition as crucial in the overall development of epistemological beliefs. There are a couple of studies providing preliminary support for such claim. Smith et al. (2000) compared two sixth-grade science classes which followed different curricula throughout their elementary years: one reflected a constructivist view and the other was a traditional science curriculum. The former placed particular emphasis on developing students' metaconceptual thinking. The analysis of interviews with the students on their views of the nature of the science revealed that the students who went through the constructivist curriculum showed more mature views of the nature of science as compared with their counterparts who went through the traditional curriculum. Similar to Smith et al.'s (2000) study, Wyre's (2007) dissertation compared classes in a community college that implemented metacognitive components with those that did not implement metacognitive teaching. Using Schommer's (1993) SEQ at the beginning and end of a semester, Wyre (2007) found that the students who went through metacognitive teaching showed significant improvement in two of the four dimensions as measured by the SEQ: quick learning and fixed ability.

While the above two reviewed studies suggested the potential influence of long-term metacognitive teaching on learners' epistemological development, they did not focus exclusively on metaconceptual intervention – there were quite many other variations in the learning environment in both studies. If a study can focus on

metaconceptual intervention, it may provide a more accurate answer in terms of the effects of metaconceptual intervention on learners' epistemological development.

To summarize this part of the literature review, while solid empirical support is lacking, there is a possible relation between metaconceptual thinking and epistemology beliefs, and it is possible that the relation is bidirectional. Specifically, on one hand epistemological beliefs may act like a thinking disposition that affects learners' engagement in metaconceptual thinking; on the other hand, long-term exposure to metaconceptual intervention may also improve one's epistemological beliefs, especially domain-specific epistemological beliefs, given the review earlier about the malleability of domain-specific epistemological beliefs. More studies are needed to provide more solid evidence regarding the linkage between the two constructs.

General Summary

In this part of the literature review, the intertwined relationship between metaconceptual thinking, epistemological beliefs, and conceptual change are closely examined. Between metaconceptual thinking and conceptual change, while literature does imply the importance of metaconceptual thinking in conceptual change, few studies to date have singled out the construct to exclusively confirm its impact. Between epistemological beliefs and conceptual change, existing studies suggest the impact of epistemological beliefs on conceptual change, although specific dimensions were not pinpointed. Finally, with regard to the relationship between metaconceptual thinking and epistemological beliefs, existing literature implies a bidirectional relationship: epistemologically advanced individuals may be more adept in metaconceptual thinking,

while long-term metaconceptual intervention may also contribute to individuals' epistemological development.

Given the above theoretical background, it would be fruitful for this study to implement metaconceptual intervention and explore how such intervention, learner's epistemological beliefs, and the possible interactions between the two impact conceptual change learning outcomes. Further, it may also be worthwhile to explore whether the metaconceptual intervention would make a difference on learners' domain-specific epistemological development.

Situating the Study: Simulation-Based Inquiry Learning

This study was situated in the context of simulation-based inquiry learning. The reason for situating the study in a simulation-based inquiry learning environment was two-fold. Theoretically, inquiry learning is often used to promote science learning. Situating the study in the context of simulation-based inquiry would provide insights into the major constructs involved in this study as well as their inter-relationships. Practically, computer simulations and inquiry learning are increasingly being used in today's science education, while science teachers are often not fully prepared to capitalize on simulations and inquiry learning as new pedagogical agents. Findings from this study may provide research-based guidelines as to the design and implementation of inquiry learning and relevant computer tools. In this part of the literature review, I first define inquiry learning and computer simulation, and then review literature on the connections between simulation-based inquiry learning and the two learning goals pursued in this study: conceptual change and epistemological development.

Defining Inquiry Learning and Simulation

Inquiry learning in science, or sometimes called discovery learning, is “a way of learning in which knowledge acquisition is based on the induction of domain rules through structured experimentation” (de Jong, 2005, p. 225). Science inquiry is a complex process in which students often engage in scientific reasoning activities such as defining a problem, making hypotheses, designing and conducting experiments, obtaining and making sense of data from observation, applying the results, and making predictions based on results (Friedler, Nachmias, & Linn, 1990). During inquiry learning, various cognitive tools can be used to assist the inquiry process. Simulation is one of such tools.

According to Alessi and Trollip (2001), simulation is “a model of some phenomenon or activity that users learn about through interaction with the simulation” (p.213). Computer simulations are often associated with inquiry learning. They generally support the “what if” situation; students can manipulate components or variables to see consequences, and thus draw inferences and discover relationships to help them build mental models of the concepts and processes under investigation.

Simulations have been a common tool among scientists to support their scientific investigations. Linking to the earlier discussions on students’ inability to “think like scientists,” computer simulations have the potential to bridge the gap by providing students with the opportunity to engage in the common practice by scientists – to interact and experiment with simulations. As Wiser and Amin (2002) have nicely put it, simulation enables students to learn not only science content, but also the nature of science models and the practice of scientists. Corresponding well to the different perspectives on conceptual change as described earlier, simulation-based inquiry has the

potential to approach conceptual change not only cognitively, but also epistemologically and socioculturally.

It is important to note that, simulation itself is a neutral term – simulation-based learning does not warrant itself to be inquiry learning. It is the way in which simulation is implemented in a learning environment that matters. Simulation can be used in a very didactic way in which learners follow recipe-like steps with limited or no inquiry activities or it can be fully used as an inquiry tool (Rezaei & Katz, 2002; Windschitl & Andre, 1998). While inquiry learning and computer simulations can be fertile ground to promote conceptual change and epistemological development, the design of a simulation-based inquiry learning environment is critical to achieve the goals.

Inquiry Learning, Simulation, and Conceptual Change

Inquiry learning emphasizes actively engaging learners in authentic learning experiences in a meaningful way (Duit, 1999). In inquiry learning, students participate in authentic science practice, work on meaningful tasks, generate hypotheses, design and conduct experiments, build models, discuss and evaluate evidence, and draw conclusions. Presumably, with active engagement and negotiation of the meaning throughout this process, cognitive conflict may appear more meaningful to learners and their preconceptions may more likely be exposed, all of which satisfy the conditions for conceptual change.

Empirical studies have been conducted to investigate the effects of inquiry learning on conceptual change. Some studies found promising results. For example, White (1993) used a set of computer microworlds with increasing complexity to engage sixth-grade students in a collaborative inquiry of prediction, experimentation,

formalization, and generalization activities. The learning outcomes were encouraging – it was found that the sixth graders who went through the inquiry learning demonstrated better conceptual understanding about force and motion than high school students who received traditional instruction. In Smith, Snir, and Grosslight's (1992) study, sixth graders learned to differentiate the concepts of weight and density by engaging in inquiry with computer-based models and simulations. The study found a moderate effect of the instructional intervention on students' conceptual change. Hsu (2008) compared students' understanding about seasonal change between two types of technology-supported learning environments, one was teacher-guided and the other was a student-centered inquiry. Student-generated concept maps revealed that the student-centered approach which allowed for free exploration led to the students' better conceptual understanding of seasonal changes when compared with the other approach. Similarly, Windschitl and Andre (1998) compared the use of simulation in objectivist and inquiry learning and found that the inquiry approach resulted in significantly greater conceptual change in two of six identified misconceptions.

However, not all inquiry learning leads to positive conceptual change learning outcomes. Some found no advantage of simulation-based inquiry learning in facilitating or sustaining conceptual change. For example, Tao and Gunstone (1999b) engaged students in *predict – observe – explain* tasks while learning force and motion with computer simulations. The collected data suggested that most students' conceptions were not stable after the intervention, vacillating from one context to another, suggesting problems with conceptual change and transfer. Hsu and Thomas (2002) compared three groups of students in a beginning meteorology course – a control group, a group using

simulation, and a group using simulation and having additional access to a log that recorded their previous actions. Quantitative analysis showed no difference among the three groups.

The positive and negative findings of inquiry learning lead one to question what makes a simulation-based inquiry successful in promoting learning, particularly conceptual change. As de Jong (2005) argued, learner guidance is necessary to ensure learners interact with simulation in a productive and manageable manner. Rezaei and Katz's (2002) study provided some evidence for the benefits of guided inquiry. The study compared a guided model of using simulation with two other approaches – a conventional approach that was lecture-based and placed emphasis on facts and formula, and a radical constructivist approach in which students were left to play with simulations on their own. The study found that the guided model led to better conceptual learning than the other two approaches. Thus neither conventional instruction nor radical approach fully taps the potential of simulation-based inquiry learning, and guided inquiry may be a better approach.

Linking inquiry learning to conceptual change and our earlier review of metaconceptual thinking, it becomes reasonable to ask whether metaconceptual guidance implemented throughout a simulation-based inquiry process would facilitate conceptual change. While letting students play with computer simulations without any guidance is not likely to lead to conceptual change, a general inquiry guide that lacks explicit metaconceptual support may also be inadequate for conceptual change to occur and to be sustained. Learners may not be aware of their own preconceptions before interacting with a simulation, and they may not be able to recognize and reflect on any conflicting results

when they are faced with dissonance that emerges in exploring the simulation.

Metaconceptual knowledge and processes may be the key to conceptual change as students learn with computer simulations. There is reason to postulate that metaconceptually-enhanced computer simulation may lead to learners' more meaningful interaction with computer simulations and thus promote conceptual change in science learning.

While to my knowledge there is no study that explicitly implemented metaconceptual guidance in inquiry learning to examine its effects on conceptual change, a closer look at some studies revealed the role metaconceptual thinking might play in inquiry learning. For example, in Tao and Gunstone's (1999a) case study on students' collaborative learning with computer simulations, it was found that conceptual change was evident among those students who were cognitively engaged and prepared to reflect on and reconstruct their conceptions. In another study, Li, Law and Lui (2006) found that teacher's provision of appropriate dissonance (e.g., questions to help students identify discrepancies between their own model and the real phenomena) at certain points during the students' inquiry with computer modeling tools was effective for conceptual change. Further, in Wiser and Amin's (2001) qualitative study it was found that metaconceptual lessons after students' interaction with simulation helped to capitalize on what they had learned from simulation.

Taken together what has been reviewed so far, because inquiry learning affords the opportunity to engage learners in a theory building process through hypothesis, experimentation, observation, and analysis, it has high potential to promote conceptual change. However, inquiry learning without guidance is not likely to facilitate learning. In

the context of conceptual learning, metaconceptual guidance has special value as compared with general inquiry guidance. While no existing study provides empirical evidence for such claim, a study comparing inquiry learning with or without metaconceptual guidance would be a worthwhile endeavor.

Inquiry Learning, Simulation, and Epistemological Beliefs

With simulation-based inquiry learning, learners have the opportunity to engage in authentic science practice and manipulate simulation as scientific tools. With such experience, learners may become more mature in their beliefs about the nature of knowledge and knowing in the field of science (Mason, 2002).

There are a limited number of studies that have examined how inquiry learning facilitated epistemological development (e.g., Carey, et al., 1989; Smith, et al., 2000). Of particular interest is the study conducted by Conley et al. (2004), in which fifth-grade students went through a nine-week science unit with hands-on scientific investigations. The researchers observed that the guide provided to the teacher that was supposed to help them teach the unit did not provide explicit instructions on how to facilitate the students' "thinking" process. As a result, the teacher was observed to emphasize the observation and exploration aspects of inquiry learning, while argumentation and reflection did not receive due attention. Students' epistemological beliefs in science measured at the beginning and the end of the nine-week period revealed that while students' beliefs in the certainty and source of knowledge improved as the result of the intervention, their beliefs in the *Development* and *Justification* of knowledge did not show significant improvement. Conley et al. (2004) postulated that the lack of improvement in the *Development* and *Justification* dimensions of epistemological beliefs might be linked to the lack of

emphasis on argumentation and reflection in the learning process. As such, students did not have enough opportunity for metaconceptual reflections in order to make sense of the science activities.

While more research is needed to replicate Conley et al.'s (2004) study, their study nonetheless suggested two points that warrant further contemplation. First, it appears that both classroom teachers and existing instructional materials may not be fully equipped to facilitate students' thinking process in science inquiry. To be more specific, in the case of using computer simulations to support science inquiry, teachers and existing instructional materials may not have sufficient capability to fully make use of the simulation tool. The second point drawn from the study is closely linked to the first one – if students' reflective thinking is not facilitated in the inquiry process, it may affect their epistemological development. Therefore, would a simulation-based inquiry learning environment that emphasizes metaconceptual thinking lead to enhanced epistemological development?

In summary, while few studies investigated the effects of science inquiry learning on promoting learners' epistemological development, existing studies suggested such possibility. Moreover, it is possible that metaconceptual intervention during the science inquiry process may play a role in epistemological development.

Now, based on the earlier review of the intertwined relationship between metaconceptual thinking, conceptual change, and epistemological belief, as well as the review in this section about simulation-based inquiry learning as a situating context, the next section presents the research questions for this study.

Research Questions

This study was conducted in eighth-grade science classes. The study focused on students' conceptual change and closely related belief change as important learning outcomes in a simulation-based inquiry learning environment. Specifically, the study aimed to test, in the context of simulation-based inquiry learning, the effects of metaconceptual intervention and learners' general epistemological beliefs on conceptual change. Further, this study also explored the possible effects of metaconceptually-enhanced, simulation-based inquiry on learners' development of science epistemological beliefs. The research questions that guided this study are presented below.

General Question

How do students' domain-general beliefs about knowledge and learning, metaconceptually-enhanced simulation-based inquiry learning, and the interaction between the beliefs and the intervention contribute to students' knowledge and belief change in science?

Operational Questions

1. Which instructional approach promotes better conceptual change in science: simulation-based inquiry learning or metaconceptually-enhanced simulation-based inquiry learning?
2. Do students' general epistemological beliefs have an effect on conceptual change during simulation-based inquiry learning as well as metaconceptually-enhanced simulation-based inquiry learning?

3. Does each of the instructional approaches, simulation-based inquiry learning approach and metaconceptually-enhanced simulation-based inquiry learning approach, have an effect on students' science epistemological beliefs respectively?

For Question 1, it was hypothesized that inquiry learning would promote conceptual change, but metaconceptually-enhanced simulation-based inquiry learning would lead to better conceptual change outcome.

For Question 2, it was hypothesized that general epistemological beliefs would have an effect on conceptual change. Further, it was postulated that epistemologically more advanced students would benefit more from additional metaconceptual intervention.

For Question 3, it was hypothesized simulation-based inquiry learning would promote students' development of science epistemological beliefs. Further, it was postulated that additional metaconceptual intervention would enhance simulation-based inquiry in promoting more mature science epistemological beliefs than simulation-based inquiry alone.

CHAPTER 3: PILOT STUDY

Introduction

While laboratory-based research does well to concentrate on study variables by excluding the “noise” that is common in real life settings, laboratory findings often cannot be translated directly into school settings. In order to increase the ecological validity of research findings, it was decided that this study be conducted in authentic, complex social context in order to realize two intertwined goals: to implement and refine theory-based learning environment and to develop theories from the study of the learning environment (Design-Based Research Collective, 2003).

Since this study aimed at implementing an innovative, simulation-based instructional intervention in authentic science classrooms, it necessarily involved the messiness as found in any naturalist environment. To ensure successful implementation of the innovative learning environment, a pilot study was first conducted to (a) test run the instructional intervention and materials in real classroom settings in order to identify any potential implementation issues, (b) examine any emergent behaviors of students as they were immersed in the learning environment, (c) explore the research questions in a pilot environment, (d) actively engage students and teachers as research partners, and (e) eventually draw implications to refine and redesign the learning environment for the main study. After a detailed description of the study design and research participants, as well as the context, this chapter details the instructional intervention and instruments used in the pilot study. The chapter ends with a report of findings and implications, based on which the main study was implemented.

Study Design

This study aimed at investigating the effects of students' general epistemological beliefs (EB) and metaconceptually-enhanced, simulation-based inquiry learning on students' conceptual change and the development of science EB. Particularly, the study was intended to identify relationships between several independent variables (metaconceptual intervention, simulation-based inquiry, and general EB) and dependent variables (conceptual change and science EB) by comparing two learning environments: metaconceptually-enhanced simulation-based inquiry (META+SBI) and simulation-based inquiry alone (SBI). The nature of the study lent itself to a quantitative research method. Further, since this study was conducted in a school setting where students were randomly assigned to one of the two conditions by their intact classes, a quasi-experimental study approach was applied (Mertens, 2005). Table 1 summarizes the study design and instruments for each research question.

Table 1

Pilot Study Research Questions, Study Design, and Instruments

Research Question	Design	Instruments
1. Which instructional approach promotes better conceptual change in science: simulation-based inquiry learning or metaconceptually-enhanced simulation-based inquiry learning?	• Pretest-posttest design	• Multiple-choice conceptual pretest and posttest • Concept mapping pretest and posttest
2. Do students' general epistemological beliefs have an effect on conceptual change during simulation-based inquiry learning as well as metaconceptually-enhanced simulation-based inquiry learning?	• Correlational design	• Multiple-choice conceptual pretest and posttest • General EB survey
3. Does each of the instructional approaches, simulation-based inquiry learning approach and metaconceptually-enhanced simulation-based inquiry learning approach, have an effect on students' science epistemological beliefs respectively?	• Pretest-posttest design	• Science EB pretest and posttest

Research Participants, Context, and Curriculum

This research was approved by both the university's Institutional Review Board (IRB) and the IRB office of the school district. All the IRB procedures and guidelines were followed in recruitment and study. Forty-three eighth-grade students (16 females and 26 males) were recruited from a middle school in the school district. The particular school and grade level were chosen because of convenient access. It was decided that the students who did not consent to participating in the study would still remain in their respective classes; however, no data were to be gathered from the non-participating students.

The forty-three eighth-grade students were recruited from two science inquiry classes of an elective course taught by two different teachers. According to the teachers, a considerable number of students were enrolled in this course because the other electives were filled up. Therefore, the students' motivation in taking the science inquiry course varied. The two intact classes were randomly assigned to either the META+SBI or the SBI treatment condition. The two treatment conditions are explained later in this chapter.

Physics, as part of the eighth-grade physical science curriculum, was selected as the instructional subject in the current study. White (1993) argued that physics was an ideal subject to introduce to students the enterprise of science. Further, physics is also the foundation of engineering and science disciplines (National Research Council, 2001). Yet, many feel that physics is the most abstract and difficult subject among all the science subjects, which is beyond the capability of most primary and secondary students (B. Y. White & Frederiksen, 1998). Research has often found that traditional physics classes fail to help students to learn physics (B. Y. White, 1993) because overemphasis is placed on

quantitative problem solving while students' qualitative understanding is often neglected (National Research Council, 2005). In such a context, simulation-based inquiry learning has great potentials in improving physics learning because it provides an environment in which students can actively engage in experimenting and building qualitative, mental models of the phenomena under study. In physics, the topics of motion and force are closely related to daily life. It is well documented that because of their familiarity with the phenomena, students often develop misconceptions based on their life experience (e.g., Hapkiewicz, 1992; Hestenes, et al., 1992). Thus, force and motion were chosen as specific instructional topics to be addressed in this study. The specific instructional content in this study followed the Oklahoma Priority Academic Student Skills (PASS) eighth-grade standards, which include both science process (e.g., Observe , Measure, Experiment, and Interpret) and physical science standards (e.g., Motions and Forces). A complete list of relevant eighth-grade PASS standards can be found in Appendix A.

Before participating in this research, the students had not learned any of the eighth-grade science content related to motion and force. Therefore, they had little knowledge of the topics to be learned. The research participants were expected to learn the content solely from the instructional intervention during this study. In other words, the instruction of motion and force would be completely delivered through simulation-based inquiry activities instead of being taught by the two science teachers. This arrangement not only allowed me to study the effects of the instructional intervention, but also minimized the possible variations different teachers might bring to the study.

Instructional Intervention

Both treatment groups (SBI and META+SBI) engaged in inquiry learning by interacting with computer-based simulations. While the two groups used the same computer simulation programs, they received different versions of web-based simulation guides that were intended to help learners with the inquiry activities. Compared with the simulation guide for the SBI group, the simulation guide for the META+SBI group contained additional metaconceptual components which are explained next.

Computer Simulations

The students in both treatment groups used the same two computer simulations to explore the topics of motion and force. The two simulations were developed by the Physics Education Technology (PhET) project group at the University of Colorado, Boulder and were downloaded from the PhET website (<http://phet.colorado.edu/index.php>). PhET is funded by the William and Flora Hewlett Foundation, National Science Foundation, and a variety of other funding agencies. It offers a variety of open-source science and math educational simulations that are free for the public to use. The design of the simulations was based on the past research on how students learn and extensive studies with individual student users (e.g., Adams et al., 2008a; Adams et al., 2008b; National Research Council, 2000).

Two PhET simulations were chosen for this study: *Moving Man* and *Forces in 1 Dimension*. Both simulations operate on the Java platform, which can be installed on a computer and accessed offline. Both simulations provide multiple types of visual representations. Take the *Moving man* for example, once launched, the interface provides three types of visual representations. At the top, there is an image of a man in a walking

position, as if walking from the left side of the screen, where there is a tree, to the right side of the screen, where there is a house. The graphics on the top part represents the man's motion, which is the first type of visual display. The second type of visual display is the motion graphs depicting the man's position, velocity, and acceleration over time. The last visual element in this interface is several numerical input boxes, which allow a user to assign a value to the man's position, velocity, or acceleration and then click a Go button to run the simulation. The Playback, Pause, and Rewind buttons at the bottom of the interface allow a user to replay and examine any part of a motion that had previously run. Figure 2 is a screenshot of the *Moving Man* simulation interface.

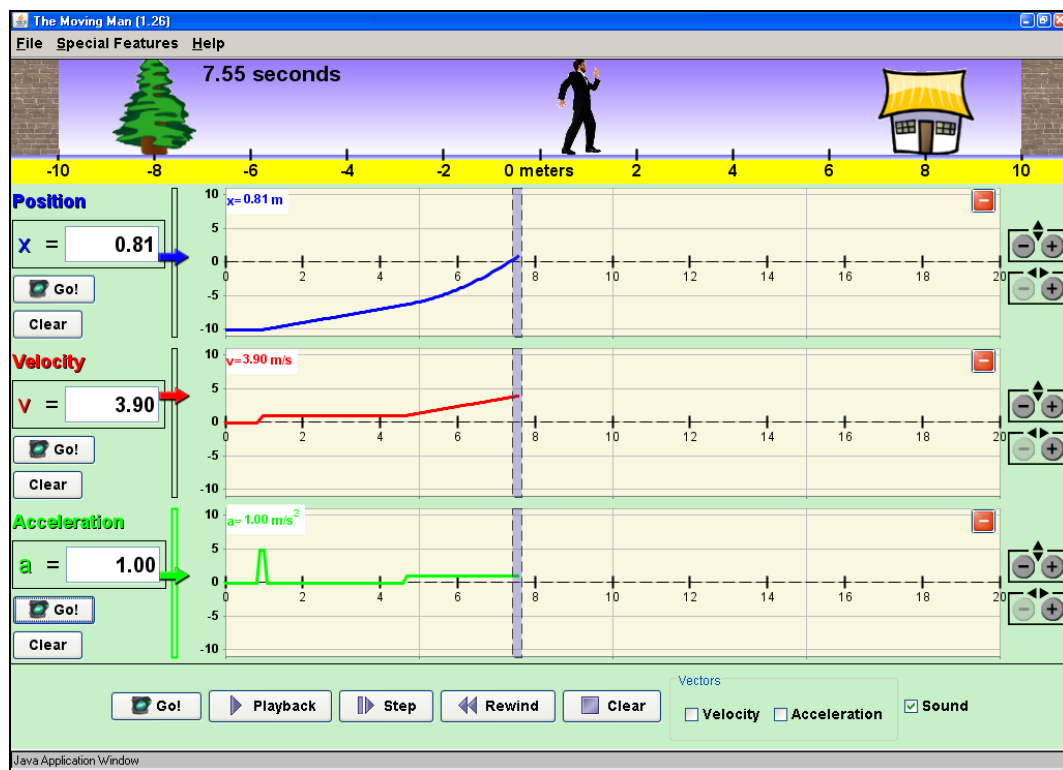


Figure 2. The Moving Man simulation interface

The PhET simulations allow students to conduct virtual experiments – they can adjust a variable and observe how the change affects other variables in multiple ways.

Take the *Forces in 1 Dimension* for example, as students interacted with the simulation,

they could enter a certain value of force and apply it to a visual object. The effect of the force could be examined in three ways: (a) an animation showing a man pushing an object, and depending on the amount of force, the object may or may not move; (b) the real-time graphs depicting how the force and the object's position, velocity, and acceleration change with time; (c) a vector graph illustrating all the forces acting on the object. Figure 3 shows the interface of the *Forces in 1 Dimension* simulation.

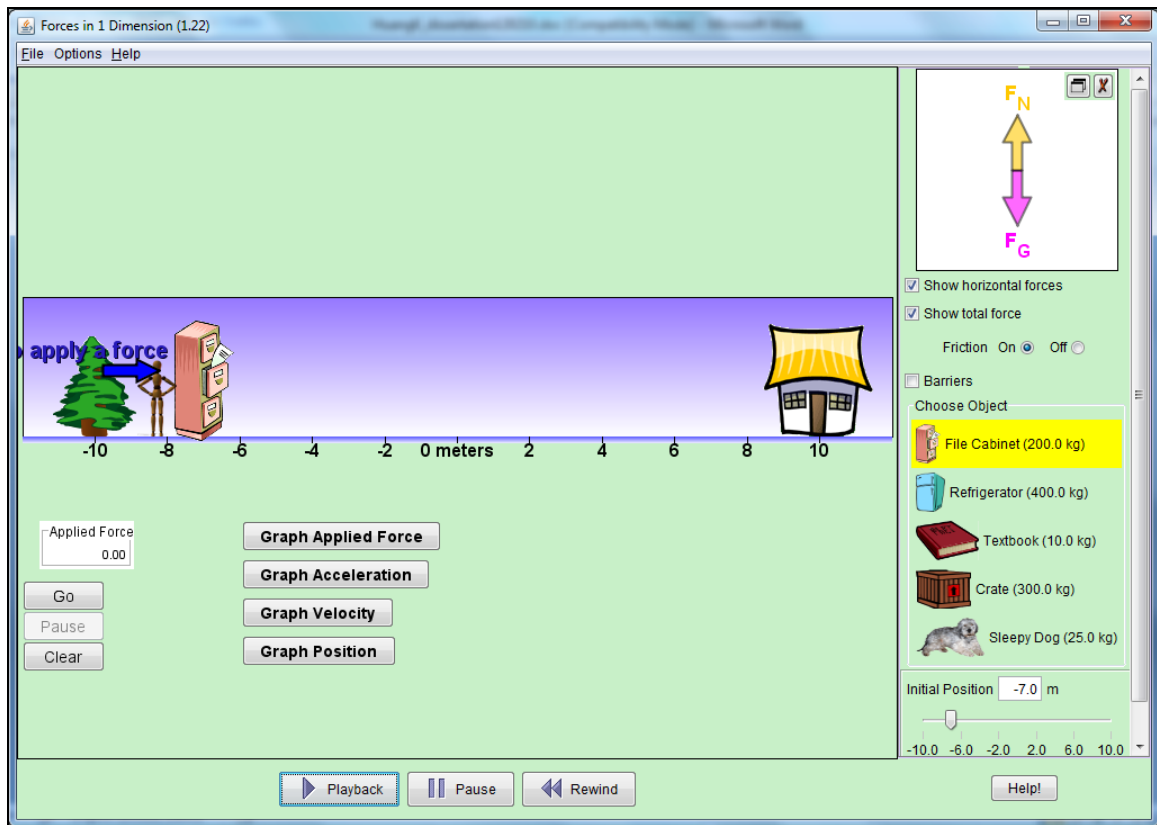


Figure 3. The Forces in 1 Dimension simulation interface

Both simulations have been tested by researchers in real classrooms (Perkins et al., 2006). In addition, the PhET website provides additional information for each simulation, including the main topics covered by the simulation, sample learning goals, and related teaching ideas. Further, users can upload and share with others their teaching ideas and instructional materials for a specific simulation.

Inquiry Activities

Using the two computer simulations, the students performed a total of six investigation units on six motion and force topics: (a) Position and Distance, (b) Position-Time Graph for At-Rest Object, (c) Constant Velocity and Velocity-Time Graph, (d) Constant Velocity and Position-Time Graph, (e) Changing Speed, and (f) Connecting Motion and Force. The students worked on certain parts of investigations each day. For each investigation, the students went through a set of inquiry activities through which they explored the force and motion topics under investigation, including making predictions, conducting and observing experiments with computer simulations, and explaining experiment findings. In addition, the META+SBI group learned additional metaconceptual knowledge, and answered additional questions regarding their metaconceptual awareness, monitoring, and evaluations during the inquiry. The students performed the investigations by following a simulation guide corresponding to their treatment condition, which is explained next.

Simulation Guide


While interacting with the same PhET simulations, the two treatment groups (SBI and META+SBI) followed different web-based simulation guides that led them through the inquiry. The two guides shared the same inquiry activities, but the guide for the META+SBI group had additional metaconceptual components throughout the inquiry.

SBI simulation guide. Part of the SBI simulation guide was adapted from the *Tools for Scientific Thinking* curriculum created by Thornton (1989). The guide had a total of six parts corresponding to the six investigations, each of which consisted of two to four web pages. While using the guide, students could navigate from one page to the

next by clicking on the buttons on the web page. Each page of the simulation guide displayed instructional text and relevant graphics. Detailed information about the simulation guide for the SBI group can be found in Appendix B1.


Each part of the simulation guide was organized around *prediction*, *observation*, and *explanation* activities. For example, in Part 3 of Investigation 3, the students explored the concepts of constant velocity and velocity-time graphs. In the *prediction* phase, the web page showed three velocity-time graphs with a question “Which of the following is a velocity-time graph for at-rest object?” The students had to select one out of four possible answers. Moving to the *observation* phase, the students were instructed to launch the *Moving Man* simulation, follow instructions to experiment with the simulation, and observe the experiment findings. The *observation* is followed by the *explanation* phase, during which students would switch back to the simulation guide window and answer the question “Did the velocity graphs agree with your prediction? If not, which of the above graphs (A, B, C) is correct?” The students had to type their answer in an input box provided on the web page. Upon submission of their answers, the students could navigate to the next page where a *What do Scientists Say* section briefly explained the main ideas in the activity. The same pattern was repeated throughout the simulation guide. To emphasize science inquiry processes, graphic icons were used throughout the simulation guide to highlight major inquiry tasks (e.g., *prediction*, *observation*, and *explanation*). As illustrated in Figure 4, the “O” and “E” icons represent the *observation* and *explanation* activities respectively. In this particular part of investigation, during the *observation* phase the students were instructed to use the *Moving Man* simulation to explore position-time graphs when the man was standing still at different positions. Upon the students’

explorations with the simulation, they came back and answered questions related to their findings. For example, they were asked what the man's position-time graph looked like when he stood still on the left side of the computer screen.




Activity 2: Position Graphs for Different At-Rest Positions

We have just observed the position graph for the man who stands to the right of the reference point. In this activity, we are going to make the man stand at different positions and observe his position graphs.



Observe

1. Open the Moving Man simulation. **Turn off** the *Velocity* and *Acceleration* graphs, leaving only the **Position** graph open.
2. Use the *Position* slider to drag the man to the *left* of the reference point. Click the **Go** button and observe the corresponding Position graph. After a little while, click the **Pause** button. Then use the *Position* slider again to move the man to the reference point, click the **Go** button again and observe the graph.
3. You may move the man to different positions as you want, just remember to click the **Pause** button each time before you change.



Explain

Based on your observations, answer the following questions:

- What does the position graph look like when the man stands still to the *left* of the reference point?

Figure 4. Screenshot showing part of the SBI group simulation guide

META+SBI simulation guide. The simulation guide for the META+SBI group shared the same number of investigation activities, web pages, and the same inquiry activities as those in the SBI simulation guide. The only difference was the addition of metaconceptual intervention, which was presented as either instructional text or question prompts at various points of the inquiry process. To make the metaconceptual components salient to the META+SBI students, each metaconceptual section was presented under a banner that included an image of a magnifying glass and a *Click to*

Check Your Understanding message. When students clicked on the banner, they would see a drop-down panel which contained metaconceptual information and/or questions. Figure 5 shows a drop-down panel with a metaconceptual question displayed inside (Note: In Figure 5, the first paragraph, which defines the concepts of velocity and constant velocity, appears in both the META+SBI simulation guide and the SBI simulation guide. The only difference with the META+SBI simulation guide is the addition of metaconceptual question that follows the first paragraph.).

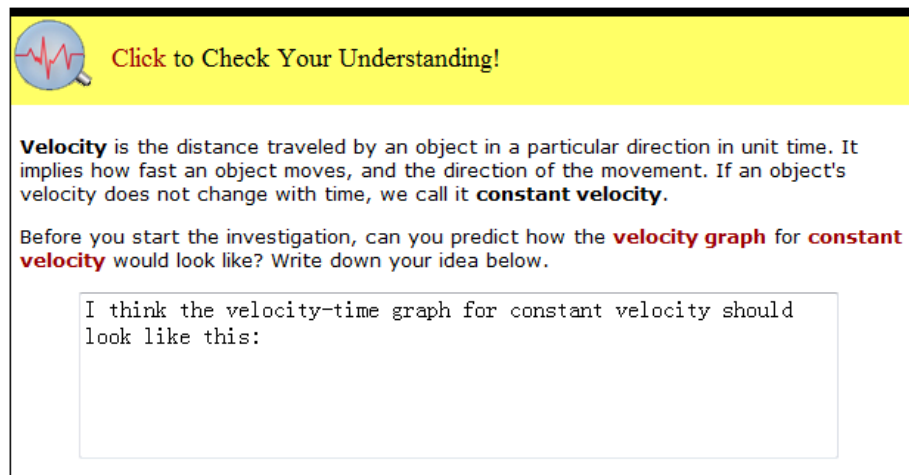


Figure 5. A panel with a metaconceptual question displayed inside

The metaconceptual intervention was designed by referring to Yuruk et al.'s (2008) taxonomy and other researchers' work on metaconceptual thinking as reviewed earlier in Chapter Two, with specific consideration of the context for this study (simulation-based inquiry). The following metaconceptual knowledge and processes guided the design of the META+SBI simulation guide:

1. Metaconceptual knowledge
 - 1.1 The importance of examining one's preconceptions
 - 1.2 One's idea as the object of thinking
 - 1.3 One's idea is subject to change with new evidence
 - 1.4 Existence of different ideas
 - 1.5 Status of one's understanding

- 1.6 The use of simulation to help understand concept
2. Metaconceptual awareness
 - 1.1 Awareness of one's existing ideas
 - 1.2 Awareness of the reasoning behind one's idea
 - 1.3 Awareness of one's experience associated with an idea
 - 1.4 Awareness of the relationship between ideas
 - 1.5 Awareness of the missing knowledge
3. Metaconceptual monitoring
 - 3.1 Monitoring the ideas from other sources
 - 3.2 Monitoring the inconsistency between one's idea and ideas from other sources
 - 3.3 Monitoring changes to one's idea
4. Metaconceptual evaluation
 - 4.1 Evaluate the status of an idea

As reviewed earlier, literature suggested that question prompting could be a promising strategy to scaffold students' metaconceptual thinking (e.g., Ge & Land, 2003, 2004; Lin, 2001). Therefore, this study used question prompts to scaffold each of the above-listed metaconceptual aspects. Table 2 illustrates with examples the scaffolding framework in the META+SBI simulation guide. Detailed information about the simulation guide for the META+SBI group can be found in Appendix B2.

Table 2

Metaconceptual Intervention in the META+SBI Simulation Guide

Metaconceptual thinking	Intervention & Examples
Metaconceptual knowledge	<p>Instructional text, stories or questions that taught students about metaconceptual knowledge in simulation-based inquiry context. Students were reminded of the metaconceptual knowledge throughout learning.</p> <p><i>Examples:</i></p> <p><i>1.1 The importance of examining one's preconceptions, and</i></p> <p><i>1.2 One's idea as the object of thinking</i></p> <p>At the very beginning, students were given the following scenario: <i>A boy and his father were in a car accident. Both the boy and the father were injured. At the hospital, the surgeon assigned to the boy took a look at him and exclaimed, "This is my son!"</i> After trying to guess what might have happened in this scenario, the students were told that the surgeon is the boy's mother. Students were then led to a discussion that people are not always aware of our preconceptions (e.g., a surgeon is a male) which often</p>

	<p>influence how one receives new information. Students were reminded at this point that they would focus on their ideas and observe how the ideas evolve over time. Throughout the entire learning process, this point was repeatedly emphasized to students.</p> <p><i>1.3 One's idea is subject to change with new evidence, and</i></p> <p><i>1.4 Existence of different ideas</i></p> <p>Students read the story of how people started to question the flat earth theory because of new findings, which eventually led to the discovery of the round earth. In addition, in each investigation students were presented ideas by some cartoon figures (either right or wrong), and asked to judge the correctness of the ideas.</p> <p><i>1.5 Status of one's understanding</i></p> <p>At the end of the first investigation, the simulation guide used <i>the Lord of the Rings</i> movie as an example to illustrate how one can understand something (e.g., the plot in the movie) but not believe it to be true.</p> <p><i>1.6 The use of simulation to help understand concept</i></p> <p>It was explained to students how simulation could help science inquiry and they were asked to give an example of how scientists used simulation to aid research.</p>
Metaconceptual Awareness	<p>Throughout the inquiry, the students responded to questions related to their initial ideas or predictions regarding the main concepts in the investigation.</p> <p><i>Examples:</i></p> <p><i>2.1 Awareness of one's existing ideas</i></p> <ul style="list-style-type: none"> • In your opinion, what is speed? Can you define it in your own words? • Based on what you have found from simulation, what is your current theory of xxx? Write down your theory. <p><i>2.2 Awareness of the reasoning behind one's idea</i></p> <ul style="list-style-type: none"> • What is the reason for your prediction? <p><i>2.3 Awareness of one's experience associated with an idea</i></p> <ul style="list-style-type: none"> • Can you give an example of <i>distance</i>? • Explain the reason for your answer and use an example to support it. <p><i>2.4 Awareness of the relationship between ideas</i></p> <ul style="list-style-type: none"> • In your mind, are <i>distance</i> and <i>position</i> the same thing or they are different? Explain your idea. <p><i>2.5 Awareness of the missing knowledge</i></p> <ul style="list-style-type: none"> • Are you sure about your predictions? • Are you very sure about your current idea?
Metaconceptual monitoring	<p>At several points in an investigation, usually after an activity/presentation of new information/test of a prediction, when appropriate, students were asked to compare with their initial idea/prediction to see if there is any inconsistency.</p> <p><i>Examples:</i></p> <p><i>3.1 Monitoring the ideas from other sources</i></p> <ul style="list-style-type: none"> • Was there something new or something different to you from what the scientists say? • Students were asked to judge whether an idea from others was right or wrong. They were asked to explain and justify their reason. <p><i>3.2 Monitoring the inconsistency between one's idea and ideas from other sources</i></p>

	<ul style="list-style-type: none"> Does the simulation result agree with your prediction? Write down the difference between your initial idea and what you found from the simulation? Is the scientists' theory about position and distance the same as your own theory written earlier?
	<p>3.3 <i>Monitoring changes to one's idea</i></p> <ul style="list-style-type: none"> Think back to your initial understanding of acceleration. Overall were there any changes to your initial understanding? If so, explain the biggest change in this investigation.
Metaconceptual evaluation	<p>At the end of an investigation, when appropriate, students were asked to consider the status of their new understanding.</p> <p><i>Examples:</i></p> <p>4.1 <i>Evaluate the status of an idea</i></p> <ul style="list-style-type: none"> If your prediction was different from what you found from the simulation, are you ready to give up your prediction and accept what you found from the simulation?

To further illustrate the difference between the simulation guides used by the META+SBI and the SBI groups, Table 3 provides a side-by-side comparison of the questions asked in the *prediction* and *explanation* parts of each simulation guide. The *observation* part only provided instructions for the students to conduct simulation experiments, and so it did not have questions. Therefore *observation* is not included in Table 3.

Table 3

META+SBI and SBI Groups Simulation Guide Comparison

Inquiry Phases	SBI simulation guide	META+SBI group simulation guide
Prediction	<i>Inquiry question</i>	
	<ul style="list-style-type: none"> Without using the simulation, can you predict the car's motion from the above Position graph? Make your selection. 	
	<i>Metaconceptual questions</i>	
	<ul style="list-style-type: none"> N/A 	<ul style="list-style-type: none"> If you are going to explain to someone why you made your prediction, what would you tell the person? Zima thinks that a position graph shows an object's moving path. She believes that the position graph above shows an object moving

		from left to right, and so A is the correct answer. Do you agree with Zima?
Explanation	<i>Inquiry question</i>	
	Based on what you found from the simulation, how would you answer the same question above?	
	<i>Metaconceptual questions</i>	
	<ul style="list-style-type: none"> • N/A 	<ul style="list-style-type: none"> • Look back at your earlier prediction, is it correct? • Based on what you found from the simulation, do you agree with Zima's idea now? • Can you explain to Zima what you found from the simulation and tell her whether she is right or wrong? Write down below what you want to say to her.

Instruments

Conceptual Evaluations

The purpose of conceptual evaluations was to measure students' conceptual change as a result of the instructional intervention in this study. The conceptual change was measured in two ways: multiple-choice conceptual test and concept mapping test. The multiple-choice conceptual test focused on specific misconceptions identified from literature, and the concept mapping test focused on the organization and interrelatedness of key concepts, namely the students' mental models. Both tests were administered twice in the pilot study as pretest and posttest.

Multiple-choice conceptual test. In order to develop an instrument to measure students' conceptual understanding of motion and force, the following list of misconceptions was identified from the existing literature (T. Brown & Crowder, n.d.; Hestenes, et al., 1992; Thorton & Sokoloff, 1998):

1. The location of an object can be described by stating its distance from a given point, ignoring direction.
2. Velocity must be positive, plotted above the time axis.

3. Students have difficulty relating real world motions to a graph and vice-versa.
4. Students plot position and velocity graphs as the path of the particle.
5. Students don't know which quantity in a graph will answer a question (e.g., coordinate or slope).
6. Constant velocity results from constant force.
7. If there is no motion, there must be no force.
8. If there is no force, there must be no motion.
9. Faster moving objects have larger force acting on them.
10. An object will slow down when the total force is zero.
11. When a force is removed from a moving object, it still has impetus on the object to keep it moving.

Corresponding to the misconceptions identified above, an 18-item multiple-choice conceptual test was developed (Appendix C1). Among the 18 items, four of them (#7-10) were selected from the Force and Motion Conceptual Evaluation (FMCE), which is a popular instrument developed by Thornton and Sokoloff (1998). FMCE is a 47-item multiple-choice instrument that diagnoses student misconceptions in one-dimensional forces and motion (Thornton & Sokoloff, 1998). The four items selected for the multiple-choice conceptual test were relevant to the domain content for this study.

In addition, two other items (#12 and 18) in the multiple-choice conceptual test were adapted from the misconception diagnosis questions developed by Brown & Crowder (n.d.) from the Student Difficulties in Physics Information Center at the Department of Physics in the Montana State University. Brown and Crowder (n.d.) reviewed physics education literature, identified a list of common misconceptions, and suggested question items that could help discover the misconceptions. Of these questions, two items were related to the instructional content in this study, and therefore they were included in the multiple-choice conceptual test.

The remaining 12 questions were adapted from the instructional materials shared by various science teachers on the PhET website. The instructional materials were

carefully reviewed and the question items that addressed the identified misconceptions in this study were selected or adapted. As a result, a total of 18 test items were reviewed, revised, and validated by four eighth-grade science teachers from two middle schools. The complete multiple-choice conceptual test and the specific misconceptions corresponding to each question item can be found in Appendix C1. The multiple-choice conceptual test was administered twice in the pilot study – pretest and posttest.

Concept mapping test. A second instrument used in this study to measure conceptual change was a concept mapping test. A concept map contains nodes that represent concepts and propositions which show the links between concepts (Novak, 1991). Studies found that concept maps created by experts are significantly different in structural complexity and organizational patterns from those created by novices (Markham, Mintzes, & Jones, 1994). Concept mapping can elicit a learner's mental model, thus it provides researchers means to examine learner's cognitive understanding and developmental change (Novak & Gowin, 1984). Concept mapping has been used to study conceptual change in science education (e.g., Fellows, 1994; Hsu, 2008; Wallace, 1990). However, the existing literature suggested that concept mapping scores did not always correlate with multiple-choice tests scores, which means that the two types of assessments may measure different aspects of understanding (Markham, et al., 1994). Therefore, in this study the multiple-choice conceptual test was intended to identify students' specific misconceptions on motion and force while the concept mapping test was intended to assess the depth and width of students' understanding about the relationships among key ideas in motion and force. It was expected that the two

instruments would complement each other to provide a complete picture of students' conceptual change learning outcomes.

During the concept mapping test, students were given a scenario of a child who became curious about how a car could move in different ways, and was asked to use a concept map to illustrate how force causes different motions of a car. Students were given 10 sticky notes, each of which showed one of the 10 concepts (nodes) (i.e., Force, Balanced Forces, Unbalanced Forces, Total Force = 0, Total Force \neq 0, At Rest, Constant Speed, Changing Speed, Speeding Up, and Slowing Down). The selection of the 10 nodes was based on Yuruk's (2005) study in which students learned similar force and motion concepts. Students were assigned three tasks for the concept mapping test: (a) arrange the sticky notes in a way that would help them to explain how force affects a car's motion, (b) draw causal links between the two sticky notes (nodes) that they thought were connected, and (c) write down the specific relationships between the two linked sticky notes they had completed in (b). The complete concept mapping test can be found in Appendix C2. The concept mapping test was administered twice in the pilot study – pretest and posttest.

Epistemological Beliefs Survey

As one of the independent variables in this study, students' general EB were measured using the Epistemological Beliefs Survey (EBS) developed by Wood and Kardash (2002). According to DeBacker et al. (2008), there are three major EB instruments – EBS, Schommer Epistemological Questionnaire (SEQ), and Epistemic Beliefs Inventory (EBI) (Schraw, et al., 2002). While all three have their own psychometric issues, EBS appears to fare better than others (DeBacker, et al., 2008). The

EBS consists of 38 self-report Likert-scale items that were drawn from the SEQ (Schommer, 1990) and another instrument developed by Jehng, Johnson, and Anderson (1993). EBS loads on five factors: *speed of knowledge acquisition* (8 items, e.g., “If something can be learned, it will be learned immediately”), *structure of knowledge* (11 items, e.g., “It’s a waste of time to work on problems that do not have a clear-cut answer”), *knowledge construction and modification* (11 items, e.g., “Today’s facts may change tomorrow”), *characteristics of successful students* (5 items, e.g., “Some people are born good learners; others are not”), and *attainability of objective truth* (3 items, e.g., “If scientists try hard enough, they can find the answer to almost every question”). Wood and Kardash (2002) and DeBacker et al. (2008) reported internal consistencies of .73 to .76 for the speed of knowledge acquisition subscale, .71 to .76 for structure of knowledge, .65 to .67 for knowledge construction and modifications, .58 to .63 for characteristics of successful students, .51 to .55 for attainability of objective truth. The instrument was coded in a way that lower scores represented more mature beliefs.

Since EBS has been mainly used with undergraduate and above level students, the question items were rephrased or modified to accommodate the eighth-grade students’ reading level. I referred to Schommer-Aikins et al.’s (2000) middle school version of SEQ to help me revise the items. In addition, I sought input from a science teacher and worked collaboratively with a professor in educational psychology to revise the items. These revised items were then reviewed by another science teacher and tested with several middle school students. The final version of the EBS can be found in Appendix C3. The EBS was administered to students at the beginning of the pilot study.

Science Epistemological Beliefs Survey

To measure students' science EB as one of the dependent variables in this study, an instrument used by Conley et al. (2004) was adopted for the study (Appendix C4). The instrument was originally developed by Elder (2002) and was later adapted by Conley et al. (2004). In both cases, the instruments were used with elementary students; therefore the items are suitable for the reading comprehension level of middle school students. Further, in Conley et al.'s (2004) study the instrument was used to measure changes in elementary students' science EB after a 9-week instruction in a science unit featuring hands-on activities. Given the similarities between Conley's study and this study in research participants, context, and purposes, this instrument served well for the current study.

Similar to the EBS, the science EB survey is a self-report Likert-scale questionnaire. It measures science EB along four dimensions: *Source* (5 items, e.g., "Whatever the teacher says in science class is true"), *Certainty* (6 items, e.g., "All questions in science have one right answer"), *Development* (6 items, e.g., "Sometimes scientists change their minds about what is true in science"), and *Justification* (9 items, e.g., "Good answers are based on evidence from many different experiments"). There are a total of 26 items in the survey. The internal consistencies of the instrument reported by Conley et al. (2004) are .81 to .82 for *Source*, .78 to .79 for *Certainty*, .57 to .66 for *Development*, and .65 to .76 for *Justification*. Similar to the EBS, this instrument was also coded in a way that lower scores indicated more mature beliefs while higher scores indicated less mature beliefs. The science EB survey was administered twice in the pilot study – pretest and posttest.

Procedure

As stated earlier, the two intact eighth-grade science classes were randomly assigned to one of two treatment groups. Specifically, the first-hour science inquiry class was assigned to the META+SBI group, and the second-hour class was assigned to the SBI group.

Figure 6 shows the overall procedure of this study. The study lasted a total of nine school days with one 45-minute class each day. As illustrated, on Day 1, a total of four instruments were administered to students in both classes in the following order: concept mapping pretest, multiple-choice conceptual pretest, general EB survey, and science EB survey pretest.

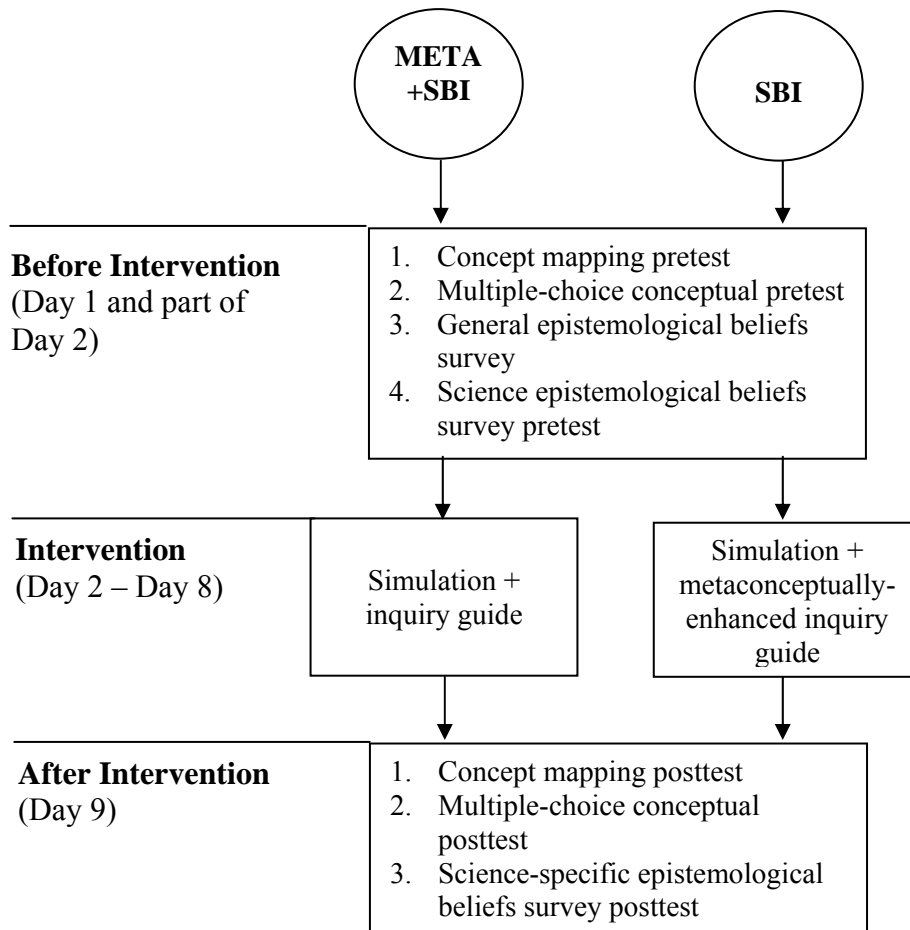


Figure 6. Pilot study procedure.

The concept mapping pretest was administered first. I first walked the students through the creation of a concept map using concepts (i.e., nodes) that they were familiar with (e.g., trees, oxygen, wood, humans, plants, animals, houses, paper, and furniture). The example concept map can be found in Appendix D. Once the students had clear understanding about creating concept maps, they were given the instruction for the concept mapping task, that is, using a concept map to explain to their younger siblings how force was related to different motions of a car. Detailed instruction can be found in Appendix C2. Each student was then provided with a stack of 10 sticky notes and a big piece of construction paper. Each of the sticky notes had one of the 10 motion and force concepts written on it. Then, the students started to work individually, arranging the sticky notes, drawing links, and explaining relationships.

For the written multiple-choice conceptual pretest, the students were told not to be concerned if they did not know how to answer the questions since they had not studied the content yet. However, they were encouraged to try their best to answer the questions.

For the two written EB surveys, the students took the science EB survey pretest first, followed by the general EB survey. When they were taking the general beliefs survey, I asked the students to think about their learning in general. When they were responding to the science beliefs survey questions, I prompted the students to think about their science learning experience in particular. The four instruments took the entire Day 1 and part of Day 2.

On Day 2, after all the participating students completed the four instruments, I demonstrated and explained to students the first computer simulation (*Moving Man*) and

the accompanying web-based simulation guide. Afterwards, each student was given an ultra mobile portable computer (UMPC) where the *Moving Man* simulation was already loaded, and the students spent some time playing with the simulation. Once the students became familiar with the simulation, they were instructed to open a web browser and access the web-based simulation guide via a provided URL, and log on using their pre-assigned ID and password. In the remaining time of the second class, I led the students through the first part of the first investigation by verbally presenting to students the information in the simulation guide. When a simulation experiment was needed, I led the entire class in this activity by first eliciting their responses and ideas about how to conduct the experiment and then performing the experiment myself, which was projected to a projector screen. When there were questions that required students to answer, I would read the questions to them first, and then I would give them some time to type and submit their answers on their computers. At the end of the class, the students logged off the simulation guide website.

From Day 3 through Day 7, each session began with my brief review of what had been learned in the past days, followed by the students' individual self-study on their computers. The review was based on each treatment condition's respective simulation guide, and therefore was consistent with the two treatment conditions. That is, the review for the META+SBI group emphasized metaconceptual knowledge and processes, whereas the review for the SBI group did not address metaconceptual thinking. During the self-study time, the students worked individually on the investigations by following their respective simulation guide, that is, they made predictions, conducted and observed simulation experiments, and answered questions throughout the process.

During this process, it was found that students' progress was slower than what was originally planned, either due to the slow progress of some individual students or because of technical issues, such as the UMPC battery running out or other technical problems. Based on students' actual progress and discussions with the teachers, I eliminated the last three parts of the sixth investigation.

On Day 8, I reviewed with the students the first five investigations that they had gone through in the past several days, and then took the lead in guiding the students through the sixth investigation which contained two parts. The teaching format was similar to that of Day 1. The review and guidance were consistent with the respective simulation guide for each treatment condition.

On Day 9, the students took three posttests: the concept mapping posttest, the multiple-choice conceptual posttest, and the science EB survey posttest. All the three instruments were the same as those used in the pretest.

During the entire process, the science teacher of each class remained in the classroom, but did not participate in any teaching activities. However, I talked with the teachers at the end of each class and consulted with them when it was necessary to make an instructional decision or a change.

Results

Coding and Scoring

Before processing data, I conducted data screening. Upon examination of the data and student attendance record, I removed from the dataset one student who missed three out of seven learning sessions, which was considered a significant amount of the learning experience. As a result, there were a total of 42 participants remaining in the dataset.

The student-generated concept maps were transferred into an Excel spreadsheet for further data processing. Specifically, each of the ten concepts (nodes) in the concept map was coded with a letter from A to J, and every proposition (pair of linked concepts) in a concept map was entered into the spreadsheet. For example, in a concept map, the node Force (coded as A) might be connected to Balanced Forces (coded as B) and Unbalanced Forces (coded as C). Thus in the spreadsheet, “A” would be entered in the *Node 1* column and “B” would be entered in the *Node 2* column for the first proposition (Force – Balanced Forces). Similarly, for the second proposition (Force – Unbalanced Forces), “A” and “C” would be entered in respective columns. Figure 7 illustrates a partial concept map and the corresponding data entry.

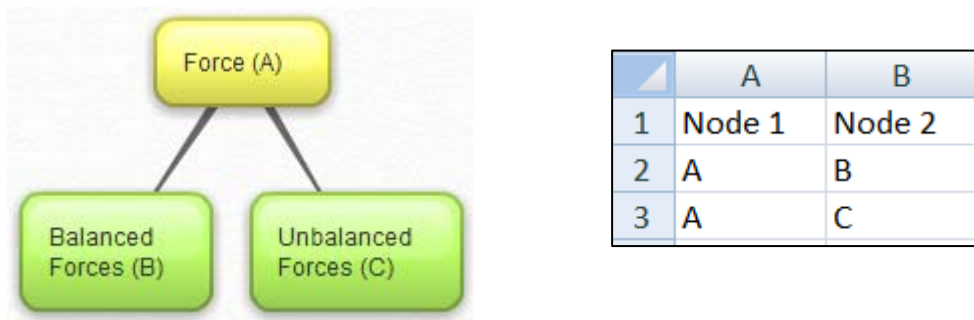


Figure 7. Concept map data entry example.

In this way, all the nodes and propositions in a concept map were recorded in the spreadsheet. Further, each concept map was given a unique ID, and pretest and posttest data were also uniquely identified. Appendix E shows a complete concept map and its corresponding spreadsheet data entry.

Once all the concept maps were coded into spreadsheets, they were analyzed using the HIMATT (Highly Integrated Model Assessment Technology) methodology. HIMATT is an automated computer-based system that analyzes and compares the structural and semantic characteristics of concept maps (Pirnay-Dummer, Ifenthaler, &

Spector, 2009). While concept maps have been used to investigate conceptual change (e.g., Fellows, 1994; Hsu, 2008; Wallace, 1990), its scope of use in quantitative studies was limited mainly because of the amount of work involved in coding concept maps. Compared to other concept map analysis techniques (e.g., Novak & Gowin, 1984), the automated nature of HIMATT enables the ability to analyze large numbers of concept maps in a time-effective manner. For this study, HIMATT performed computer-based calculations and generated six scores for each student-created concept map, representing six dimensions of a concept map (Eseryel, Ifenthaler, Ge, Law, & Guo, 2009). Four of the six dimensions – *Surface*, *Graphical*, *Gamma*, and *Structural Matching*, together compared the *structure* of a concept map with that of an expert. The other two dimensions – *Concept* and *Propositional Matching*, measured the *semantic* similarities between a student's concept map and an expert's map. In this particular study, student-generated concept maps were compared against an expert concept map that was based on Yuruk's (2005) study (see Appendix F for the expert concept map). The comparison resulted in six matching indexes which ranged from 0 to 1.

An explanation of each HIMATT dimension is provided below. For detailed information about the HIMATT and its six dimensions, refer to Eseryel, et al. (2009), Ifenthaler (2008), Kopainsky, Pirnay-Dummer, & Alessi (2010), and Pirnay-Dummer (2010).

1. Surface matching: The surface value represents the number of links (between two concepts) within a concept map. Among the three concept maps in Figure 8, A has one link, and therefore its surface value is 1. B has a total of 4 links, and therefore B's surface value is 4. C's surface value is 7 (a total of 7 links). Surface

value is a simple and easy indicator of a map's surface complexity by showing how large a concept map (representing a mental model) is. *Surface Matching* is obtained by comparing the surface value of a concept map with that of an expert map.

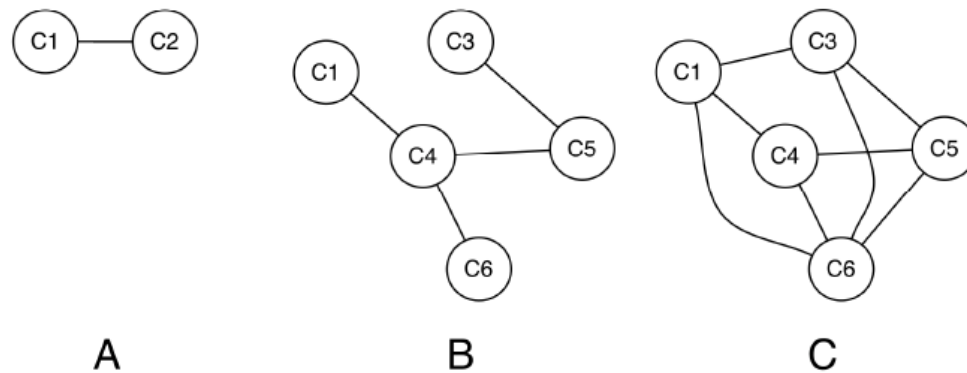


Figure 8. Three example concept maps.

Reprinted from “Automated assessment of learners’ understanding in complex dynamic systems,” by B. Kopainsky, P. Pirnay-Dummer, & S. Alessi, 2010, Paper presented at the 28th International Conference of the System Dynamics Society, Seoul, Korea, p.13.

2. Graphical matching: The graphical value calculates the diameters of the spanning trees of a map. A diameter is “the quantity of links of the shortest path between the most distant nodes” in a map (Ifenthaler, 2008, p. 86). For the concept map B in Figure 8, its graphical value is 3 (C1-C4-C5-C3). For a concept map with cycles (or loops) inside (e.g., concept map C in Figure 8), HIMATT would remove the loops when calculating the graphical value so that the map’s complexity would not be discounted because of the presence of the loops.

Graphical value is an indicator of the range of conceptual knowledge displayed in a map, or the “width” of a map. *Graphical Matching* is obtained by calculating

the similarity index between the graphical value of a concept map and that of an expert map.

3. Gamma matching: The gamma value is calculated as the number of nodes per link within a graph. In Figure 9, concept map A's gamma value is 2 (6 nodes, 3 links) and B's gamma value is 0.4 (6 nodes, 15 links). Gamma value is an indicator of the density, or the internal connectedness of a concept map. In Figure 9, concept map A only connects pairs of concepts, and map B connects every concept with all the other concepts (everything with everything). Both types of concept maps are considered weak mental models, and therefore a medium density is expected for most good working models. *Gamma Matching* is obtained by calculating the similarity index between the gamma value of a concept map and that of an expert map.

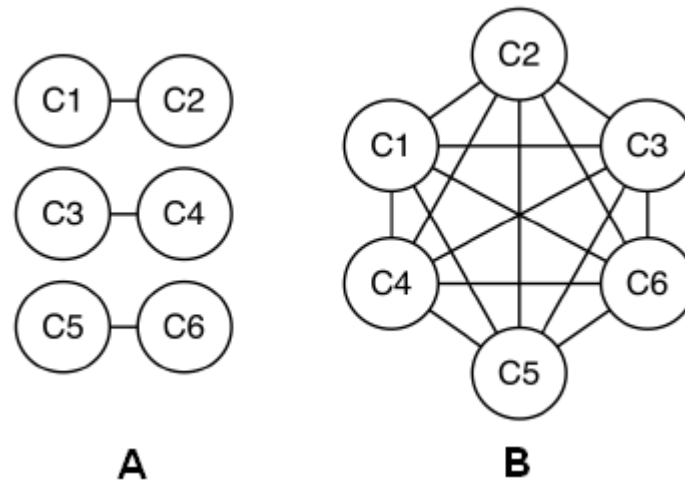


Figure 9. Two concept maps illustrating *Gamma Matching*.

Reprinted from “Automated assessment of learners’ understanding in complex dynamic systems,” by B. Kopainsky, P. Pirnay-Dummer, & S. Alessi, 2010, Paper presented at the 28th International Conference of the System Dynamics Society, Seoul, Korea, p.18.

4. Structural matching: Structural value represents the overall structure of the map regardless of the content. It is the most complex structural measure among the four HIMATT structural measures (Pirnay-Dummer, 2010). It detects the differences between two maps that other structural measures are not capable of detecting. For example, the three concept maps in Figure 10 have the same surface and graphical values (5 and 3 respectively), which means that the two measures cannot distinguish the structural differences which are clear to human eyes. However, the structural index is able to distinguish the difference. The structural index “retraces every structural component and analyzes the structure based on the basis of its parts” (Pirnay-Dummer, 2010, p. 239). Because of the exponential complexity involved in its calculation, *Structural Matching* is limited to analyzing concept maps of small or moderate size. Given that the concept mapping task in the current study only involved 10 concepts, this measure worked well for the study.

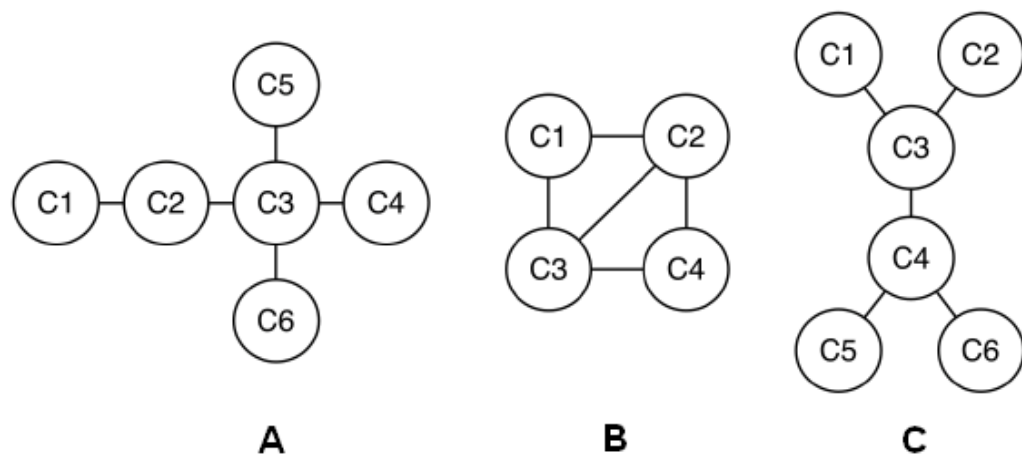


Figure 10. Comparison of three concept maps.

Reprinted from “Automated assessment of learners’ understanding in complex dynamic systems,” by B. Kopainsky, P. Pirnay-Dummer, & S. Alessi, 2010, Paper presented at the 28th International Conference of the System Dynamics Society, Seoul, Korea, p.16.

Structural Matching accounts for the internal structure of a concept map – how different concepts are integrated in one’s mental model. It is a good indicator of the extent to which a map demonstrates expert-level knowledge structure.

According to Kopainsky et al. (2010), this measure is necessary for studies with assumptions that expert knowledge is structured differently from novice knowledge. The measure was shown to predict expertise (Pirnay-Dummer, 2010).

On the other hand, one should keep in mind that the measure is about graphical structure only – it does not account for any semantic aspects of a concept map.

5. Concept matching: *Concept Matching* counts how many concepts are alike between two concept maps. It determines the differences in language use between models and shows the semantic correctness of a concept map. Since in the current study students constructed concept maps using the same 10 pre-assigned concepts provided to them, the *Concept Matching* measure was of little value to the study.
6. Propositional matching: *Propositional Matching* searches for and compares only fully identical propositions (concept-link-concept) between two concept maps. For example, if in the expert concept map two concepts *unbalanced forces* and *changing speed* are linked to each other, and if the two concepts are also linked in a student concept map, then there is a match between the two concept maps in this particular proposition. *Propositional Matching* is an indicator of the semantic similarity between two concept maps.

The six HIMATT measures have been used to study how learners' externalized cognitive structures develop over time or change as a result of instructional interventions (e.g., Eseryel, et al., 2009; Ifenthaler, 2010; Ifenthaler, Masduki, & Seel, 2009). The reliability and validity of the HIMATT measures have been established in past studies (e.g., Eseryel, et al., 2009; Ifenthaler, 2010).

Of note particularly are the multiple measures of the HIMATT technology. Other concept mapping assessment techniques such as the method suggested by Novak and Gowin (1984) typically measure four aspects of concept maps: (a) presence of relevant concepts, which is said to indicate the breadth of the concept; (b) propositional linkages, which are said to represent the interconnectedness or complexity of knowledge; (c) the number of levels emanating from the center node, which is said to represent the depth of knowledge; and (d) misconceptions, which is based on identifications of any misconceptions present in a concept map (Miller et al., 2009; Novak, 1991). Compared with these measures, the HIMATT technique measures some additional dimensions that otherwise might not be detected, e.g., the *Structural Matching* index.

As explained earlier, since the *Concept Matching* index was of little meaning to the current study, *Concept Matching* was eliminated from further data analysis. As a result, there were only five measures (*Surface*, *Graphical*, *Gamma*, *Structural*, and *Propositional Matching*) to examine students' cognitive structure.

For the multiple-choice conceptual tests, since the last three parts of the sixth investigation were eliminated, three questions (#15, 17, 18) that were related to the eliminated parts were removed from the original test. Students' pretest and posttest were scored based on the remaining 15 items. The total possible points for the conceptual test

were 15, with 1 point for each correct answer. Since this study focused on conceptual change which represented radical restructuring of one's initial conceptual framework, those students who held considerable misconceptions were of main interest in the study. In introducing a frequently used instrument to measure force and motion concepts – the Force Concept Inventory (FCI), Hestenes et al. (1992) suggested that only those students who scored less than 60% would qualify as a valid sample. Referencing to this approach, one student who scored above 60% in the multiple-choice conceptual test was removed from further data analysis. 41 students remained as the valid samples for the pilot study.

For the two EB instruments, reverse items were re-coded and the subtotals for each factor were calculated. For the general EB survey, the total scores were also calculated.

After all the data were cleaned, scored, and coded, the following variables for each student were compiled in the final SPSS data file: (a) treatment group, (b) multiple-choice conceptual test scores (pretest and posttest), (c) concept mapping test scores (five dimensions; pretest and posttest), (d) general EB survey scores (overall and five subscales), (e) science EB survey scores (four subscales; pretest and posttest).

Preliminary Data Analysis

Because intact classes were used in this pilot study without real random assignment of each student to the two treatment groups, preliminary analyses were conducted to ensure that the two classes were comparable in all the pretest measures.

To examine whether the two treatment groups had any significant difference in the multiple-choice conceptual pretest, a one-way analysis of variance (ANOVA) was conducted. The ANOVA was not significant, $F(1, 33) = .36, p = .55$.

To examine whether the two treatment groups had any significant difference in the concept mapping pretest, a one-way multivariate analysis of variance (MANOVA) was conducted. No significant multivariate difference was found between the two treatment groups, Wilk's $\Lambda = .86$, $F(5, 28) = .95$, $p = .47$. Analysis of variances (ANOVA) on each HIMATT measure did not show any significant group difference.

To examine whether the two treatment groups had any significant difference in the science EB pretest, a one-way multivariate analysis of variance (MANOVA) was conducted. No significant multivariate difference was found, Wilk's $\Lambda = .90$, $F(4, 27) = .71$, $p = .59$. Analysis of variances (ANOVA) on each individual measure did not show any significant group difference.

Overall, the preliminary data analysis did not reveal any pretest difference between the two treatment groups across all the dependent variables in this study, which led to the conclusion that before the intervention, the two groups were about equal on the dependent variables under investigation.

Data Analysis

Table 4 summarizes the data sources and data analysis approaches for each of the three research questions. Results of each research question are reported thereafter.

Table 4

Pilot Study Data Analysis Framework

Research Questions	Data Sources	Data Analysis
1. Which instructional approach promotes better conceptual change in science: simulation-based inquiry learning or metaconceptually-enhanced simulation-based inquiry learning?	<ul style="list-style-type: none"> • Scores on multiple-choice conceptual pretest and posttest • Scores on concept mapping pretest and posttest (5 dimensions) 	<p>Repeated-measures ANOVA (for multiple-choice conceptual tests) and repeated-measures MANOVA with follow-up repeated-measures ANOVA's (for concept mapping tests):</p> <ul style="list-style-type: none"> • Within-subject factor: time, 2 levels (pretest and posttest)

		<ul style="list-style-type: none"> Between-subject factor: treatment group, 2 levels (SBI, META+SBI)
2. Do students' general epistemological beliefs have an effect on conceptual change during simulation-based inquiry learning as well as metaconceptually-enhanced simulation-based inquiry learning?	<ul style="list-style-type: none"> Total scores on general EB survey Scores on multiple-choice conceptual pretest and posttest 	<p>Multiple regression</p> <ul style="list-style-type: none"> Predictors: conceptual pretest scores, general EB total, treatment group, and General EB x Treatment interaction term. Dependent variables: multiple-choice conceptual posttest scores
3. Does each of the instructional approaches, simulation-based inquiry learning approach and metaconceptually-enhanced simulation-based inquiry learning approach, have an effect on students' science epistemological beliefs respectively?	<ul style="list-style-type: none"> Scores on the science EB pretest and posttest: 4 dimensions 	<p>Repeated-measures MANOVA with follow-up repeated-measures ANOVA's</p> <ul style="list-style-type: none"> Within-subject factor: time, 2 levels (pretest and posttest) Between-subject factor: treatment group, 2 levels (SBI, META+SBI)

Question 1. Which instructional approach promotes better conceptual change in science: simulation-based inquiry learning or metaconceptually-enhanced simulation-based inquiry learning?

Since students' conceptual change was measured with two instruments: a multiple-choice conceptual test and a concept mapping test, the students' performance in the multiple-choice conceptual test was examined first. Table 5 presents the means and standard deviations for the conceptual tests.

Table 5

Means and Standard Deviations of Conceptual Test, Concept Mapping Test, and Science EB Survey in the Pilot Study

Instrument	META+SBI	SBI
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Subscales	Pretest	Posttest	Pretest	Posttest
Multiple-Choice Conceptual Test				
	3.67 (1.45)	6.87 (3.02)	3.60 (2.37)	5.00 (2.71)
Concept Mapping Test				
Surface	.91 (.08)	.93 (.08)	.92 (.12)	.88 (.13)
Graphical	.80 (.18)	.80 (.13)	.75 (.23)	.81 (.14)
Structural	.85 (.13)	.81 (.22)	.83 (.20)	.98 (.06)
Gamma	.88 (.11)	.93 (.12)	.91 (.17)	.90 (.09)
Propositional	.39 (.14)	.41 (.19)	.35 (.22)	.34 (.18)
Science EB				
Source	11.43(3.92)	7.50 (2.18)	10.40 (3.95)	11.30 (4.45)
Certainty	10.21 (3.40)	7.64 (2.31)	11.40 (5.93)	11.10 (5.36)
Develop	10.07 (3.08)	9.36 (4.14)	10.30 (3.06)	11.00 (4.55)
Justify	15.50 (3.92)	17.93 (8.20)	15.90 (5.49)	17.90 (5.70)

The mean scores of the META+SBI group increased from 3.67 in the pretest to 6.87 in the posttest. Comparatively, the SBI group's pretest and posttest mean scores were 3.60 and 5.00 respectively. From the descriptive data, it appears that both groups of students made improvement in the multiple-choice conceptual test from pretest and posttest, and that the META+SBI group seemed to achieve more than the SBI group.

To statistically investigate the treatment effects on the students' multiple-choice conceptual test, a repeated-measures ANOVA was conducted with treatment group as a between-subject and time as a within-subject factor. Repeated-measures analysis allows researcher to examine change over time while controlling for variations in dependent variables due to individual difference (Stevens, 2002). In addition, repeated-measures analysis is more powerful and requires fewer subjects. This was especially advantageous, given that the pilot study did not have a large sample. Mauchly's test indicated that the

assumption of sphericity was met, $p > .05$. The repeated-measures ANOVA indicated a significant main time effect, Wilk's $\Lambda = .63$, $F(1, 23) = 13.47$, $p < .01$, partial $\eta^2 = .37$, which suggested that students from both treatment groups made significant improvement from pretest to posttest. However, there was no significant main treatment effect, $F(1, 23) = 1.56$, $p = .22$, partial $\eta^2 = .06$, nor significant Treatment x Time interaction effect, Wilk's $\Lambda = .92$, $F(1, 23) = 2.06$, $p = .16$, partial $\eta^2 = .08$.

Students' performance on the concept mapping tests was examined next. The two treatment groups' pretest and posttest means on the five HIMATT measures are shown in Table 5. To statistically investigate the treatment effects on learners' concept mapping performance, a repeated-measures MANOVA was conducted on the five HIMATT dimensions (*Surface*, *Graphical*, *Structural*, *Gamma*, and *Propositional Matching*). Multivariate analysis showed no significant treatment effect, Wilk's $\Lambda = .74$, $F(5, 19) = 1.31$, $p = .30$, no significant time effect, Wilk's $\Lambda = .83$, $F(5, 19) = .76$, $p = .59$, nor Treatment x Time interaction effect, Wilk's $\Lambda = .64$, $F(5, 19) = 2.13$, $p = .11$. Follow-up univariate tests indicated a significant Treatment x Time interaction effect on *Structural Matching*, $F(1, 23) = 4.48$, $p < .05$, $\eta^2 = .16$. However, the interaction effect favored the SBI group. While the SBI group's *Structural Matching* scores improved in the posttest, the META+SBI group decreased in performance.

Question 2. Do students' general epistemological beliefs have an effect on conceptual change during simulation-based inquiry learning as well as metaconceptually-enhanced simulation-based inquiry learning?

This question was intended to find out the impact of students' general EB and their interaction with treatment groups on the students' conceptual change learning

outcomes. Multiple linear regression analysis was performed to answer this question. Given the small sample size in this pilot study, it was not feasible to enter all the five dimensions of general EB as predictors. Therefore the sum total of all the five dimensions was entered as one single predictor. The General EB x Treatment interaction term was created by multiplying the total scores of the students' general EB with the treatment group variable. Both general EB total and treatment group variable were centered in order to avoid multicollinearity. Visual inspections of residual errors suggested that the assumptions of linearity and homogeneity of variance were met. Kurtosis and skewness for each variable was within the reasonable range which indicated that the normality assumption was met. Regarding the multicollinearity assumption, tolerance statistics ($> .10$) and VIF values (< 10) indicated that the assumption was met.

Predictors of the students' multiple-choice conceptual posttest scores were entered in the following hierarchical order: multiple-choice conceptual pretest score at the first level, general EB total at the second level, treatment group at the third level, and finally, the General EB x Treatment interaction at the fourth level. In the first step, pretest did not appear as a significant predictor, $R^2 = .05$, adjusted $R^2 = .005$, $F(1,22) = 1.12$, $p = .30$. In the second step with added general EB, the model was significant, R^2 change = $.35$, $F(1,21) = 6.89$, $p < .01$. The effect size was large. Specifically, general EB was a significant predictor, $b = -.16$, $p < .01$, as well as pretest, $b = .59$, $p < .05$. In the third and fourth steps, treatment and General EB x Treatment interaction did not predict significantly over and above the previous models.

Table 6 shows the correlations among the variables, and Table 7 provides a summary of the regression analysis.

Table 6

Correlations between Regression Analysis Variables in the Pilot Study

Variable	1	2	3	4	5
1. Posttest	–	.22	-.52**	-.34	.28
2. Pretest		–	.23	-.03	.003
3. General EB			–	.02	-.01
4. Treatment group				–	-.22
5. EB x Treatment					–

** $p < .01$

Table 7

*Summary of Hierarchical Regression Analysis for Variables Predicting Conceptual**Posttest in the Pilot Study*

Predictor	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>p</i>
Step 1 ($R^2 = .05$)					
Pretest	.36	.34	.22	1.06	.30
Step 2 ($R^2 = .40$, $\Delta R^2 = .35$)					
Pretest	.59	.29	.36	2.07	.051
General EB	-.16	.05	-.61	-3.48	.002**
Step 3 ($R^2 = .50$, $\Delta R^2 = .10$)					
Pretest	.57	.27	.35	2.14	.045*
General EB	-.15	.04	-.60	-3.65	.002**
Treatment group	-1.94	.98	-.32	-1.98	.06
Step 4 ($R^2 = .54$, $\Delta R^2 = .04$)					
Pretest	.57	.26	.35	2.18	.042*
General EB	-.15	.04	-.60	-3.72	.001**
Treatment group	-1.65	.99	-.27	-1.67	.11
EB x Treatment	.11	.08	.21	1.33	.20

* $p < .05$; ** $p < .01$

Research Question 3: Does each of the instructional approaches, simulation-based inquiry learning approach and metaconceptually-enhanced simulation-based inquiry learning approach, have an effect on students' science epistemological beliefs respectively?

Table 5 shows the means and standard deviations of the science EB across its four dimensions. To make comparison between the two treatment groups, a repeated-measures MANOVA was conducted on the four dimensions of science EB, with time as a within-subject factor and treatment group as a between-subject factor. No significant main time or treatment effect was found at the multivariate level. However, there was a significant Treatment x Time interaction effect across the four science EB dimensions, Wilk's $\Delta = .62$, $F(4,19) = 2.94$, $p < .05$, $\eta = .38$. Univariate analysis on the *Source* dimension showed a significant Treatment x Time effect, $F(1, 22) = 10.25$, $p < .01$, $\eta = .32$. Figure 11 shows the two treatment groups' scores on the *Source* dimension from pretest and posttest. As can be seen, from pretest to posttest, while the SBI group's mean scores slightly increased, the META+SBI group's mean scores significantly decreased, approaching more mature beliefs.

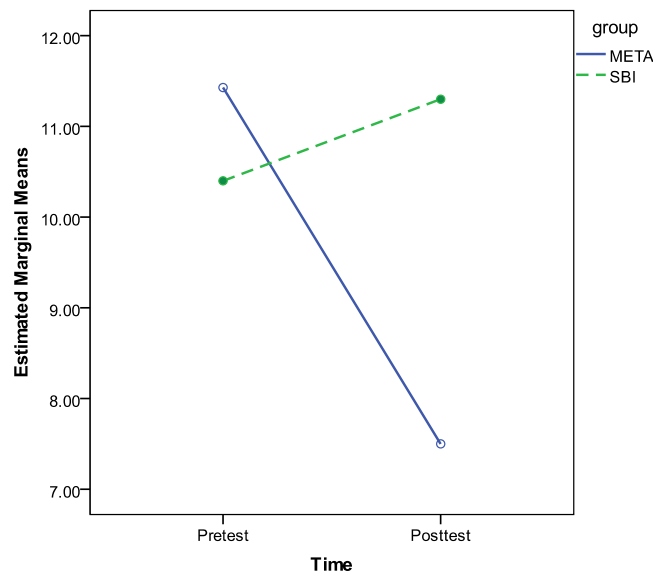


Figure 11. Pilot study science EB *Source* dimension pretest and posttest means

Additionally, univariate analysis on the *Certainty* dimension also found a significant Treatment x Time effect, $F(1, 22) = 4.96, p < .05, \eta = .18$, as well as a significant time effect, $F(1, 22) = 7.92, p < .01, \eta = .27$. From pretest to posttest, while both groups decreased in the *Certainty* belief mean scores, and the META+SBI group decreased significantly faster than the SBI group. Figure 12 shows the two treatment groups' pretest and posttest means of the *Certainty* dimension.

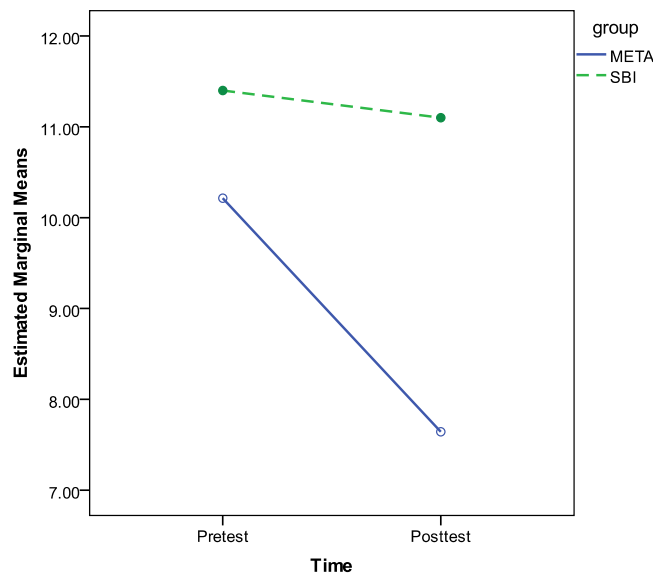


Figure 12. Pilot study *Certainty* dimension pretest and posttest means

To examine the pretest-posttest change of science EB within each individual treatment group, paired-sample t-tests were conducted within each treatment group (META+SBI or SBI). For the META+SBI group, the *Source* dimension in pretest ($M = 11.43$, $SD = 3.92$) and posttest ($M = 7.50$, $SD = 2.18$) was significantly different, $t(14) = 4.13$, $p < .01$. Similarly, the *Certainty* dimension was also significantly different between pretest ($M = 10.21$, $SD = 3.40$) and posttest ($M = 7.64$, $SD = 2.31$); $t(15) = 3.78$, $p < .01$. Since the lower the EB scores, the more mature the beliefs are, the META+SBI group students demonstrated significant improvement in their beliefs in the source and certainty of science knowledge. For the other two science EB dimensions – *Develop* and *Justify*, the META+SBI group did not show any significant pretest-posttest difference.

For the SBI group, paired-sample t-tests did not find any significant pretest-posttest difference across all the four science EB dimensions, which suggested that the students in the SBI condition did not show significant improvement in their science EB.

Discussion

This pilot study was conducted with the purpose of testing the instructional materials, instruments, and the procedure in order to identify any potential issues associated with the implementation in the main study. Additionally, the pilot study provided an opportunity to test the study design.

Interpretations of the Pilot Study Findings

Treatment effects on conceptual change. In this study, it was expected that the META+SBI group would perform better than the SBI group on the conceptual change measures, since the additional metaconceptual intervention on the META+SBI group was designed to prompt the students to become metaconceptually aware of their preconceptions and to continuously monitor and evaluate their thinking throughout their inquiry. The findings, however, did not confirm the positive effects of metaconceptual intervention.

Particularly, this study found that the META+SBI group did not show better performance than the SBI group in the multiple-choice conceptual test. This finding seemed to conflict with what is indicated in the existing studies. While few existing studies have exclusively examined the effect of metaconceptual thinking on conceptual change and even fewer were conducted in a simulation-based inquiry learning environment, they nonetheless imply that engaging learners in examining and monitoring their own thinking had potential effects on conceptual change (Biemans & Simons, 1995; Hennessey, 2003; Tao & Gunstone, 1999a; Vosniadou, 2003). The unexpected finding might be partially related to the limitations of this pilot study, such as the META+SBI

students' lack of engagement in answering metaconceptual questions. The limitations are detailed in a later section.

Further, on the *Structural Matching* measure of the concept maps, while the SBI group performed better in the posttest, the META+SBI group declined in their performance. As described earlier, *Structural Matching* is a unique, complex measure of the HIMATT technology, which is able to detect structural differences that other structural measures such as *Surface*, *Graphical*, and *Gamma Matching* fail to capture. The measure accounts for the complete structure of a concept map, indicating how the integration of concepts in a concept map compares to that in an expert concept map (Pirnay-Dummer, 2010). Thus, the decrease of the META+SBI group in *Structural Matching* suggested that the structure of, or the organization of concepts in this group of students' mental models moved further away from the expert model.

One possible reason could be that, compared to the SBI group students, the students in the META+SBI group had to process additional metaconceptual information and answer additional metaconceptual questions during their inquiry process. Given that the metaconceptual intervention focused on individual concepts (e.g., “what is speeding up and how does speeding up show in a velocity-time graph?”) or the relationship between two concepts (e.g., balanced forces and at-rest object), the META+SBI group might have engaged their cognitive resources in constructing knowledge at the individual concept level, without sufficient time or cognitive resources to focus on the *overall* structure of the key concepts that they had learned. As a result, when the old knowledge structure was going through changes, the new structure was not yet forming into a coherent whole, resulting in the META+SBI students' poorer performance. In

comparison, the SBI students only needed to focus on answering essential inquiry questions without having to allocate additional cognitive resources to process metaconceptual intervention, thus they might be able to spend more time and cognitive resources to consider the key concepts more broadly, which helped the students in this group to develop concept maps of more sophisticated structure.

With regard to the effects of simulation-based inquiry learning on conceptual change, the significant time effect on the students' conceptual test indicated that simulation-based inquiry was capable of reducing student misconceptions. The finding was consistent with some previous studies on the effects of inquiry learning on conceptual change (e.g., Smith, et al., 1992; B. Y. White, 1993). On the other hand, the SBI group's performance in concept mapping indicated that simulation-based inquiry had limited effects on the students' structural and semantic understanding of the relationships among the key concepts they had learned.

Effects of general EB on conceptual change. This study confirmed, in a simulation-based inquiry learning environment, the important role of learners' general EB in conceptual change, as students' general EB emerged as a significant predictor for the multiple-choice conceptual posttest. The finding was consistent with the findings from previous studies (Qian & Alvermann, 1995; Windschitl, 1997; Windschitl & Andre, 1998). In Windschitl and Andre's (1998) study, for example, university students used computer simulations to learn biology topics. General EB was also treated as a composite variable. The study found that general EB was a significant predictor of students' posttest scores. Thus the findings suggested that in a simulation-based inquiry learning environment, students' beliefs about knowledge and learning affected the revision of their

misconceptions. Those students who believed that learning took effort and that knowledge was complex and subject to change tended to revise their misconceptions, which was demonstrated by higher conceptual test scores; while those who believed that learning required little effort and that knowledge was simple and certain were less likely to revise their ideas, which was indicated by lower conceptual test scores.

On the other hand, however, the speculated interaction between general EB and treatment on conceptual change was not confirmed in this study. Some existing studies speculated the possible links between EB and metaconceptual thinking (Fulton & Kendeou, 2009; Stathopoulou & Vosniadou, 2007). In particular, it was suspected that students who have more mature EB tended to exhibit more metaconceptual thinking. Following the exploratory studies, this study was intended to explore whether more epistemologically mature individuals would more likely benefit from metaconceptual intervention. However, the results of this study indicated that the treatment effect on students' conceptual change did not vary according to students' epistemological maturity.

Treatment effects on science EB. This study sought to examine the effects of two treatment conditions (SBI and META+SBI) on the development of students' science EB. With some studies suggesting the potential effects of metaconceptual thinking on science EB (Smith, et al., 2000; Wyre, 2007), it was expected that the META+SBI group would outperform the SBI group on the science EB measures. The findings appeared to support this expectation in two dimensions (*Source* and *Certainty* beliefs about science knowledge) on which the META+SBI group outperformed the SBI group. Given that the META+SBI students were only exposed to the metaconceptual intervention for a short period of time (about two weeks), their improvement in science EB was promising.

The metaconceptual intervention on the META+SBI group might help to explain the group's improvement in their *Source* and *Certainty* beliefs about science knowledge. At the beginning of this study, the students learned from several stories how misconceptions might affect one's thinking and how new evidence led to theory revisions in history. Throughout their investigations with simulations, the students were prompted to monitor and evaluate their ideas, reflect on any necessary revisions to their ideas, and elaborate their own theories based on investigations. Even for those students who did not write down their answers to some metaconceptual questions, they could have still processed the questions to a certain extent. The metaconceptual thinking that the students were engaged in during the inquiry process might have shattered the students' beliefs that science knowledge comes from authority and that there is only one way to understand science. As a result, the students moved towards a more mature level of beliefs by recognizing that science knowledge comes from different sources and is subject to change.

On the other hand, simulation-based inquiry did not seem to improve students' science EB in this pilot study, as the students in the SBI group did not show any significant pretest-posttest difference in all the four science EB dimensions. This finding is contradictory to previous research findings, which suggested that immersing students in inquiry learning over a relatively longer period of time had potential to promote students' development of science EB (Carey, et al., 1989; Conley, et al., 2004). Relatively short intervention time might be one reason for the contradictive findings. Compared with previous studies which lasted several weeks, semesters, or even years,

this two-week intervention might be too short to bring about significant changes in science EB. Some other possible reasons are detailed later in the limitations section.

Limitations of Pilot Study

While the findings from this study provided some preliminary evidence to the three research questions, these findings should be interpreted with caution. The remainder of this section discusses the limitations, which can probably provide some explanations to the findings.

First, the sample size of this pilot study was small. There were only 41 students participating in the study. Some of these students missed taking one or more instruments during pretest and/or posttest, resulting in even smaller samples for data analysis. The small sample size might have contributed to the inadequate power to reject null hypotheses.

Secondly, the intended metaconceptual intervention plan was not fully implemented. Based on my class observations, interactions with individual students, and my examination of students' responses, it was revealed that only about a third of the students answered some of the metaconceptual questions, another third answered very few questions, and the remaining third did not answer any questions at all. It was also observed that some students did not closely follow the simulation guide to run simulations or answer questions as required. In addition, some students indicated that they did not understand some of the questions, and therefore they did not know how to answer them. All these factors might have resulted in the failure of metaconceptual intervention to enhance simulation-based inquiry in this pilot study.

Finally, the portable computers (UMPCs) students used for their investigations were inconvenient to use. Battery outage and technical issues frequently distracted the students from focusing on their inquiry tasks. Furthermore, the small screen display of the computers and the use of a stylus to interact with the screen made it harder for the students to perform inquiry tasks that could have been much easier on a regular PC, such as window switching between the simulation window and the simulation guide window and running experiments with simulations. The challenge was greater for the META+SBI students who had to switch the windows more frequently in order to answer the metaconceptual questions.

Additional Findings

This section reports some additional findings based on my in-class observations of student learning, which helped to improve the design of the main study.

First, it was observed that, as they approached the inquiry tasks, the students from both groups lacked systematic understanding that predictions, experiments, and explanations were logical procedures that are meaningfully linked to each other. They probably treated each of the steps as a discrete and separate procedure without making the effort to think about the relationships among all the steps. A considerable number of students approached their inquiry tasks in a haphazard manner. In other words, the students were not actively and seriously engaged in hypothesis testing, but rather they were in a “free play” mode. Similar findings were reported by Vosniadou et al. (2001), who stated that students were often not aware that their ideas were in fact hypothetical theories that were subject to verification and falsification.

The second observation was that the students in both treatment groups demonstrated a lack of awareness that the computer simulations helped them to test predictions, examine how one variable is related to other variables, and to infer theories based on simulation results. The lack of participation or only partial participation in their inquiry and sense-making processes might have contributed to the students' lack of development in their science EB, especially on the development and justification of science knowledge.

Third, it was found that the individual students worked at a difference pace, which made it difficult for me to guide all the students through the same inquiry process. In the original plan, it was decided that the inquiry learning would take a teacher-guided approach so that the students would be held more accountable for conducting the inquiry tasks. While this format worked well on Day 2, it became clear on Day 3 that it was difficult to keep all the students at the same pace. Because all the information was available in the web-based simulation guide, some students chose to work ahead or behind at their own pace without following my leading. Therefore, the two science teachers and I decided to change teacher-guided inquiry to individual inquiry by following the self-study guide. After several days of self study, however, it was observed that the students' motivation dropped. This was similar to White and Gunstone's (1989) findings that students' motivation and engagement dropped when a particular teaching format was used too long. White and Gunstone (1989) suggested bringing variations to the teaching procedure to sustain students' engagement. My informal conversations with the students also confirmed that they preferred alternating between teacher-led format and self-study format.

Lessons Learned and Potential Modifications in the Main Study

Based on the findings from the pilot study I have summarized the lessons learned. One of the major lessons learned was that the metaconceptual intervention needs to be further strengthened, and the science inquiry process must be further enhanced. Additional modeling and scaffolding were needed to help students really treat their conceptions as the object of thinking (Murphy & Mason, 2006), and to make predictions, carry out experiments, and interpret findings in a systematic manner. Several modifications were planned for the main study that is presented in the next chapter:

1. To help students of both treatment groups to understand science inquiry, establish the systematic link between predictions, experiments, and conclusions, and understand the role of simulations in inquiry activities, I would guide students through a simulation-based mini-inquiry at the beginning, through which they would experience how to start from a prediction, use simulation to test their prediction, and draw conclusions based on the findings.
2. To help the META+SBI students develop the habit and skills to reflect on their conceptual understanding and answer metaconceptual questions, I would conduct a mini-inquiry activity with additional metaconceptual questions and lead the first investigation myself in order to provide more modeling. In both cases, I would model and guide the students in answering the metaconceptual questions.
3. To address some students' misunderstanding and confusion about some of the metaconceptual questions, all the metaconceptual questions were to be further reviewed and revised by myself and two science teachers to be used for the main study.

4. To help the META+SBI students understand that one's conceptions are subject to testing and can be proven false, I would introduce more historical examples to illustrate how some common misconceptions in human history were proved to be wrong, for example, the flat earth misconception.
5. To remedy situations where students did not correctly follow instructions to conduct experiments, which possibly affected the intended results and their responses to subsequent questions, a video clip showing the correct way to run a simulation experiment was to be provided on the subsequent page of each experiment for the main study.
6. To reduce the inefficiency and interference caused by the need to frequently switch between the simulation window and the simulation guide window, it was decided that the *observation* part of the simulation guide was to be provided in a handout. By doing this, the students would be able to focus as they conduct simulation experiments
7. To encourage students' engagement in the simulated inquiry process and to increase their on-task behavior, the main study would map out a plan to alternate between instructor-guided and self-study formats for both treatment groups. By switching between reading from a computer and listening to the teacher, the students would likely pay more attention to the content and tasks.
8. To ensure an appropriate amount of learning, the last three parts of the sixth investigation and their corresponding test questions were eliminated. As a result, the new conceptual test consisted of 15 items.

CHAPTER 4: MAIN STUDY

Participants and Context

The research participants were 151 eighth-grade students from a different middle school in the same school district as the middle school where I conducted the pilot study. Therefore, the two schools shared the same curriculum. However, there were some differences in the teaching approaches between the two schools. While the students in the pilot study had been exposed more to inquiry-based learning (e.g., the prediction – observation – explanation inquiry cycle), the students in the main study had less experience with inquiry learning; the instruction was mainly dominated by lectures.

The students in the main study came from eight regular science classes in the middle school. The eight classes took place during four school hours: the first and the second hour in the morning, and the seventh and the eighth hour in the afternoon. Each hour had two classes that were combined and co-taught by two science teachers.

According to the two science teachers, the academic levels of all the eight classes were about the same. Therefore, the eight classes were randomly assigned to two experimental conditions according to school hours. Four classes with a total of 73 students from the first and the seventh hours were assigned to the SBI condition, and the other four classes with a total of 78 students from the second and the eighth hours were assigned to the META+SBI condition.

Instructional Materials and Intervention

While the computer simulations were the same as those in the pilot study, some changes were made to the simulation guide and the intervention based on the experience learned from the pilot study. The changes are highlighted in the description below.

Simulation Guide

Several changes have been made to the simulation guide. First, to ensure that the students complete all the investigations within the allocated time for this study, the last three parts of the sixth investigation on *Connecting force and motion* were removed from the original simulation guide. Second, to avoid frequent switches between the simulation window and the simulation guide window, the *observation* sections, which instructed students to conduct simulation experiments, were removed from the web-based simulation guide and presented to the students in paper format instead. Third, after the students completed each simulation experiment, a video demonstration on the proper way to conduct the experiment was made available on the subsequent web page. In this way those students who did not conduct the experiment appropriately still had a chance to see the correct way to conduct it. Finally, to avoid distraction, for all the teacher-guided investigations, the entire instructional information was removed from the corresponding simulation guide, leaving only the original questions and input boxes for the students to type their answers.

Additional Interventions

Additional interventions were introduced to both treatment groups in the main study. For the SBI group, additional mini-inquiries were introduced after the pretests and before the students started the first investigation. The purpose of the mini-inquiries was for the students to further understand the science inquiry process and the role of simulations in science inquiry. During the mini-inquiries, I guided the students to use a computer simulation, *Mouse Genetics*, to explore genetic topics. The simulation was developed by the ExploreLearning Company (<http://www.explorelearning.com/>). At the

beginning, the simulation interface showed a pure white mouse and a pure black mouse, and the students were asked to predict what the two mice's offspring would look like and write down their predictions on a piece of paper. After a brief class discussion of the students' predictions, I ran the simulation *Mouse Genetics* on a projector screen to breed the two mice. The students observed the simulation results and recorded their findings. After a second brief discussion of the simulation findings, the students were asked to go through a second mini-inquiry by predicting the offspring of a pure white mouse and a hybrid black mouse, observing the simulation, and recording the findings. At the end, I led the students to reason how predictions, experiments, and conclusions worked together in science inquiry and how simulations helped to support the inquiries.

For the students in the META+SBI group, two additional interventions were introduced. First, more examples were provided to the students illustrating how some misconceptions in the history of science were later proved to be wrong. The purpose of introducing these examples was to raise the students' awareness of science misconceptions and the need to question, test, and refute them. Three historically renowned misconceptions were introduced and refuted with simulations or examples: (a) when being dropped, a heavy ball travels faster than a light ball; (b) a heavier pendulum bob causes shorter pendulum period; (c) the earth is flat.

The second additional intervention to the META+SBI group was the *Mouse Genetics* mini-inquiries. The mini-inquiries were conducted in the same way as in the SBI group, except for the additional metaconceptual questions that the students had to answer during the inquiry. For example, when making predictions, the students were also asked to explain the reasons for their predictions. After a simulation experiment, the

students were asked to verbalize whether their predictions were supported by the experiment, in addition to recording their findings. Finally, at the end of the inquiry, the students were also asked to state whether there was any change to their initial ideas. Throughout the process, I provided guidance and modeling to help the students answer the metaconceptual questions. In addition, the students were able to share and discuss their answers during class discussions.

Format of Learning

To encourage students' engagement in learning and to increase their on-task behavior, the format of learning alternated between teacher-guided inquiry and students' independent inquiries. During the independent inquiry sessions, the students were informed at the beginning that their goal was to develop their own theories about the topics addressed in a specific investigation. The students then worked individually on their computers to read through the simulation guide, perform experiments by following the paper handout, and answer questions when necessary.

During the teacher-guided investigations, the instructional text was removed from the original simulation guide, leaving only the original questions and input boxes. I presented the instructions to the students. When it was necessary to conduct an experiment with simulation, the students ran the simulation individually on their own computers by following the paper handout. When students were required to answer questions, I verbally asked the questions to the students, and the students would then type and submit their answers from the simulation guide web page.

Special effort was made to help the students adjust to the new learning environment. During the first investigation, which was a teacher-guided session, I

provided more scaffolding to both treatment groups by walking the students through the investigation, explaining questions to the students, and demonstrating the appropriate ways to answer the questions.

Instruments

The same four instruments used in the pilot study were also used in the main study: (a) concept mapping test, (b) multiple-choice conceptual test, (c) general EB survey, and (d) science EB survey. The concept mapping test and the multiple-choice conceptual test were administered three times in the study: pretest, posttest, and delayed posttest which took place four weeks later. Additionally, the students took the science EB survey twice, one as pretest and the other as posttest. Finally, the general EB survey was conducted once at the beginning of the study.

Procedure

The procedure of the main study was similar to that in the pilot study. The study lasted a total of 10 days, with one 45-minute session per day. On Day 1 and part of Day 2, the students took all the four instruments. For the rest of Day 2, the SBI group went through the mini-inquiries introduced earlier, and the META+SBI group went through the same mini-inquiries but received additional metaconceptual intervention as described earlier.

From Day 3 to Day 9, the students worked on the six investigations. All students had laptop PCs on which they could launch the simulation required for the day and log on to the simulation guide website corresponding to their treatment conditions. Each day began with my review of the main points from the previous days. Among all the six investigations, the first, third, and sixth were led by me, and the students independently

conducted the other three investigations by following the web-based simulation guide.

On Day 10, after a brief final review, the students took three posttests: concept mapping, multiple-choice, and science EB posttests. About four weeks later, I returned to the school, and the students took two delayed knowledge tests: concept mapping and multiple-choice conceptual tests. The two science teachers informed me that during the four-week period, they did not re-teach any content covered during the intervention to any of the eight classes. All the classes moved on to the next unit on force and motion which was about momentum. In the new unit occasionally there was some opportunity for the students to apply what they had learned from the intervention, but the opportunity was equal in all the eight classes, as the two teachers continued to co-teach all the classes.

Results

Coding and Scoring

Upon an examination of the students' attendance records, 12 students were removed from the dataset because they missed at least three out of eight learning sessions which were considered a significant portion of learning. The remaining 139 students constituted the valid sample for further data analysis.

The student-generated concept map data were first transformed to an Excel spreadsheet and then were analyzed using the HIMATT technology (Ifenthaler, 2008; Pirnay-Dummer, et al., 2009). Each concept map was compared with the expert concept map, generating five HIMATT measures for data analysis: *Surface*, *Graphical*, *Gamma*, *Structural Matching* (i.e., structural measures), and *Propositional Matching* (i.e., semantic measure).

The multiple-choice conceptual pretest, posttest, and delayed posttest were graded. Similar to the pilot study, one student who scored more than 60% on the multiple-choice conceptual pretest was removed from the dataset (Hestenes, et al., 1992). The remaining 138 students constituted the valid sample for the study.

For the general EB and science EB surveys, reverse items were re-coded, and subscale scores as well as the total scores of the general EB were calculated.

The following variables for each student were compiled and entered in the SPSS statistical analysis software: (a) treatment group, (b) multiple-choice conceptual test scores (pretest, posttest, and delayed posttest), (c) concept mapping test scores (by dimensions; pretest, posttest, and delayed posttest), (d) general EB survey scores (overall and by dimensions), (e) science EB scores (by dimensions; pretest and posttest).

Preliminary Data Analysis

Since intact classes were used in the main study, preliminary data analyses were conducted to determine if there was any significant difference between the two treatment groups in the pretest.

An ANOVA was conducted to examine whether the two treatment groups had any significant differences in the multiple-choice conceptual pretest. The result showed that there were no significant differences between the two groups in the conceptual pretest, $F(1, 133) = 3.32, p = .07$.

A one-way MANOVA was conducted on the five HIMATT measures to examine whether the two treatment groups had any significant differences in the concept mapping pretest. Similar to the conceptual test, no significant multivariate differences were found,

Wilk's $\Lambda = .98$, $F(5, 130) = .51$, $p = .77$. ANOVA on each of the five HIMATT dimensions did not reveal any significant group difference.

Likewise, a one-way MANOVA was conducted to examine whether the two treatment groups had any significant difference in the science EB pretest. Significant difference was found between the two groups, Wilk's $\Lambda = .87$, $F(4, 129) = 5.08$, $p < .01$. Univariate analyses revealed significant group differences in three of the four science EB dimensions: *Certainty*, $F(1, 132) = 12.10$, $p < .01$, $\eta^2 = .08$, *Development*, $F(1, 132) = 14.48$, $p < .01$, $\eta^2 = .10$, and *Justification*, $F(1, 132) = 10.83$, $p < .01$, $\eta^2 = .08$. Specifically, the META+SBI group had significantly lower scores on the three dimensions than the SBI group, suggesting that the META+SBI group had significantly more mature beliefs about the certainty, development, and justification of science knowledge at the beginning of the study.

Because of the group difference in science EB, it became worthwhile to explore whether the two groups also differed significantly in their general EB. Thus a MANOVA was conducted on the five general EB dimensions: *speed of knowledge acquisition*, *structure of knowledge*, *knowledge construction and modification*, *characteristics of successful students*, and *attainability of objective truth*. There was no significant multivariate difference between the two groups, Wilk's $\Lambda = .96$, $F(5, 127) = 1.09$, $p = .37$. Follow-up univariate tests found significant differences between the two groups in one of the dimensions – *knowledge construction and modification*, $F(1, 131) = 4.54$, $p < .05$. The students in the META+SBI group held more mature beliefs about knowledge construction and modification than the students in the SBI group. However, the results indicated that the two groups' general EB did not differ as much as in science EB.

Later communications with the two science teachers indicated that the more mature science EB of the META+SBI group was probably because more students from the META+SBI classes were enrolled in an optional high school biology class than the students from the SBI classes were. The biology class might have contributed to the more advanced development of science EB in the META+SBI group due to more enrollments in the biology class.

Overall, the preliminary data analyses suggested that, while the two treatment groups did not differ in content knowledge, they differed significantly in science EB. This difference was taken into account when performing the subsequent data analyses.

Data Analysis

Given the pretest differences between the two treatment groups in science EB, it was decided that two sets of analyses would be conducted, with or without pretest science EB as a covariate, in order to obtain thorough understanding to the first research question and to examine the possible influence of science EB on students' conceptual change. To investigate the third research question, the science EB pretest was used as a covariate in the analysis in order to directly examine the treatment effect on science EB. Table 8 summarizes the data sources and data analysis approaches for each of the research questions.

Table 8.

Main Study Data Analysis Framework

Research Questions	Data Sources	Data Analysis
1. Which instructional approach promotes better conceptual change in science: simulation-based	<ul style="list-style-type: none"> • Scores on multiple-choice conceptual pretest, posttest, and delayed posttest • Scores on concept 	Repeated-measures ANOVA/ANCOVA (for multiple-choice conceptual tests); Repeated-measures MANOVA/MANCOVA with

inquiry learning or metaconceptually-enhanced simulation-based inquiry learning?	<p>mapping pretest, posttest, and delayed posttest (5 dimensions)</p> <ul style="list-style-type: none"> Science EB pretest total 	<p>follow-up repeated measures ANOVA/ANCOVA (for concept mapping tests)</p> <ul style="list-style-type: none"> Within-subject factor: time, 3 levels (pretest, posttest, and delayed posttest) Between-subject factor: treatment group, 2 levels (SBI, META+SBI) Covariate: science EB pretest total
2. Do students' general epistemological beliefs have an effect on conceptual change during simulation-based inquiry learning as well as metaconceptually-enhanced simulation-based inquiry learning?	<ul style="list-style-type: none"> Scores on general EB survey (5 dimensions) Scores on multiple-choice conceptual pretest and posttest 	<p>Multiple linear regression</p> <ul style="list-style-type: none"> Predictors: pretest scores, 5 general EB dimensions, treatment group, and General EB x Treatment Dependent variables: multiple-choice conceptual posttest
3. Does each of the instructional approaches, simulation-based inquiry learning approach and metaconceptually-enhanced simulation-based inquiry learning approach, have an effect on students' science epistemological beliefs respectively?	<ul style="list-style-type: none"> Scores on the science EB pretest and posttest (4 dimensions) Science EB pretest total 	<p>MANCOVA with follow-up ANCOVA</p> <ul style="list-style-type: none"> Grouping variable: treatment group Dependent variable: science EB posttest scores on 4 dimensions Covariate: science EB pretest total

Research Question 1: Which instructional approach promotes better conceptual change in science: simulation-based inquiry learning or metaconceptually-enhanced simulation-based inquiry learning?

Students' performances in the multiple-choice conceptual test were examined first.

Table 9 presents the means and standard deviations of the conceptual tests.

Table 9

Means and Standard Deviations of Conceptual Test and Concept Mapping Test

Instruments/ Dimensions	META+SBI			SBI		
	Pretest	Posttest	Delayed	Pretest	Posttest	Delayed
Conceptual Test						
	4.25 (1.98)	9.09 (3.42)	8.42 (3.23)	3.79 (1.53)	6.15 (2.89)	5.25 (2.77)
Concept Map Assessment						
Surface	.93(.10)	.95(.09)	.94(.09)	.93(.10)	.94(.10)	.95(.07)
Graphical	.78(.16)	.77(.17)	.82(.14)	.78(.13)	.83(.13)	.82(.14)
Structural	.79(.16)	.79(.17)	.85(.16)	.83(.15)	.88(.14)	.87(.16)
Gamma	.92(.12)	.93(.12)	.93(.10)	.92(.12)	.93(.11)	.94(.09)
Propositional	.45(.18)	.56(.20)	.55(.23)	.48(.18)	.55(.22)	.55(.22)

The mean scores of the SBI group for the pretest, posttest, and delayed posttest were 3.79, 6.15, and 5.25 respectively. The means scores of the META+SBI group were 4.25, 9.09, and 8.42 respectively. The descriptive data suggested that both treatment groups made significant improvement, but that the META+SBI group seemed to gain more than the SBI group.

To statistically investigate the treatment effect, a repeated-measures ANOVA was conducted on students' multiple-choice conceptual tests, with the treatment group as a between-subject and time as a within-subject factor. Mauchly's test indicated that the assumption of sphericity was met, $p > .05$. There was a significant main time effect, Wilk's $\Lambda = .40$, $F(2, 113) = 85.97$, $p < .01$, $\eta^2 = .60$, a significant treatment effect, $F(1, 114) = 28.49$, $p < .01$, $\eta^2 = .20$, and a significant Treatment x Time interaction effect, Wilk's $\Lambda = .80$, $F(2, 113) = 14.42$, $p < .01$, $\eta^2 = .20$. As shown in Figure 13, both groups

made significant improvement as a result of the intervention, and the META+SBI group made significantly more progress than the SBI group.

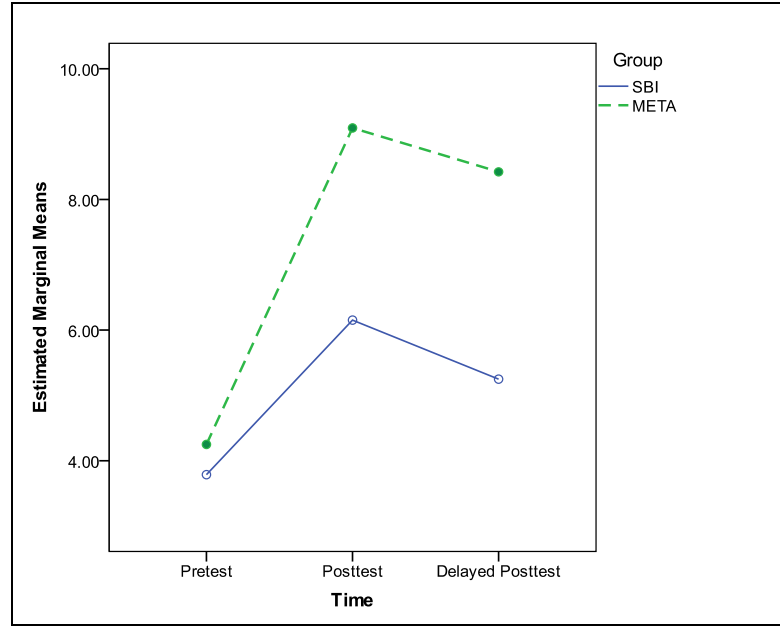


Figure 13. Main study multiple-choice conceptual test performance.

To take into account the difference of the two treatment groups in the science EB pretest, a repeated-measures ANCOVA was conducted using the pretest science EB total score as a covariate. A preliminary analysis indicated that the homogeneity-of-slopes assumption was met, $F(1,110) = .05, p = .82$. Mauchly's test indicated that the assumption of sphericity was met, $p > .05$. There was a significant main time effect, Wilk's $\Lambda = .81, F(2, 110) = 12.83, p < .01, \eta^2 = .19$, a significant treatment effect, $F(1, 111) = 15.96, p < .01, \eta^2 = .13$, and a significant Treatment x Time effect, Wilk's $\Lambda = .85, F(2, 110) = 9.91, p < .01, \eta^2 = .15$. Therefore the main time, treatment, and Treatment x Time effects remained significant even after the difference in science EB pretest was controlled.

Descriptive data for the concept mapping tests are displayed in Table 9. To statistically investigate the treatment effect on students' concept mapping performance, a repeated-measures MANOVA was conducted on the five HIMATT dimensions, with treatment group as a between-subject and time as a within-subject factor. Box's M test indicated that the homogeneity assumption was met (Box's M = 154.19, $p > .05$). Multivariate test showed significant main time effect, Wilk's $\Lambda = .79$, $F(10,108) = 2.80$, $p < .01$, $\eta^2 = .21$. There was no significant treatment or Treatment x Time effect.

Follow-up univariate tests indicated significant effects on three dimensions: *Propositional Matching*, *Graphical Matching*, and *Structural Matching*. The first dimension, *Propositional Matching*, showed a significant time effect, $F(2,234) = 8.83$, $p < .01$, $\eta^2 = .07$. Figure 14 shows that both groups of students made significant improvement in *Propositional Matching* in the posttest.

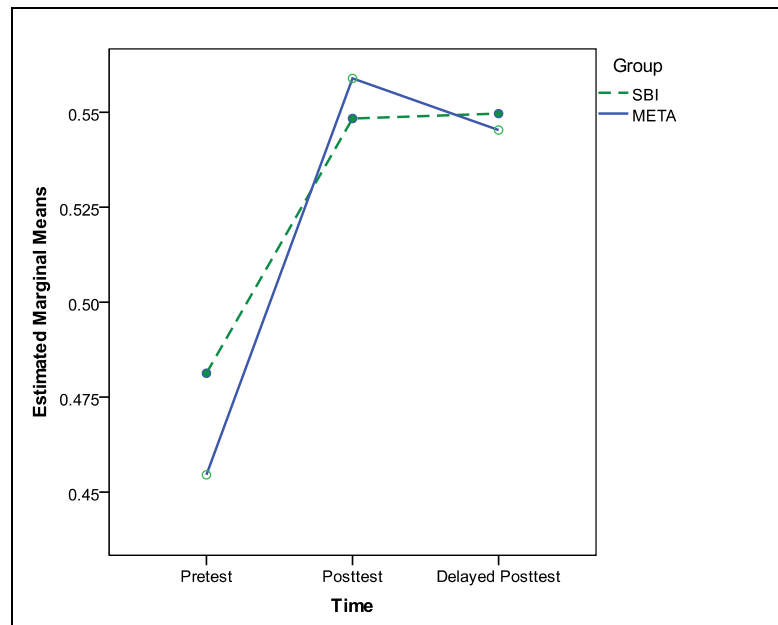


Figure 14. Main study concept mapping test performance in *Propositional Matching*

The second dimension, *Graphical Matching*, also showed significant time effect, $F(2,234) = 4.56, p < .05, \eta^2 = .04$. As shown in Figure 15, the two treatment groups exhibited different trends, although the Treatment x Time interaction was not statistically significant. SBI group made significant improvement in the posttest, but declined slightly in the delayed posttest. Comparatively, the performance of the META+SBI group decreased in the posttest, but then significantly improved in the delayed posttest.

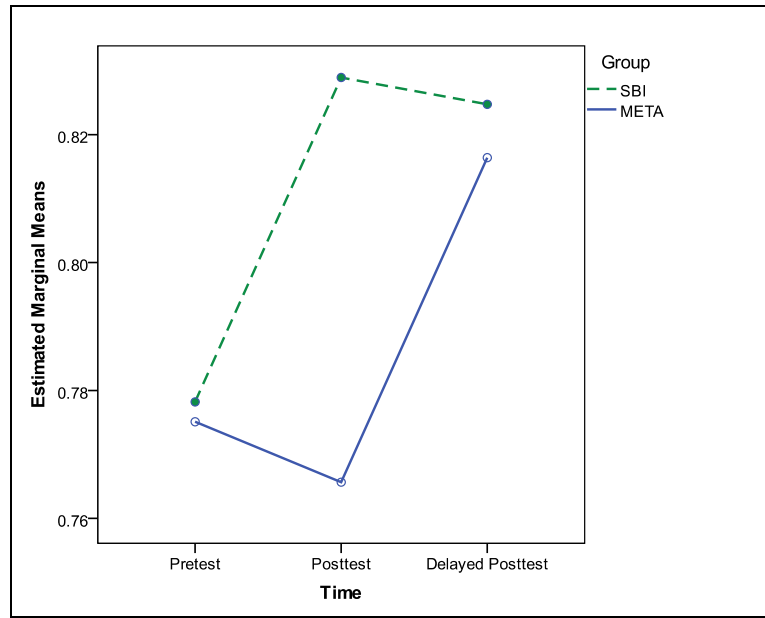


Figure 15. Main study concept mapping performance in *Graphical Matching*

The third dimension, *Structural Matching*, showed significant time effect, $F(2,236) = 5.54, p < .01, \eta^2 = .05$, treatment effect, $F(1,117) = 4.71, p < .05, \eta^2 = .04$, and Treatment x Time effect, $F(2,234) = 3.19, p < .05, \eta^2 = .03$. As Figure 16 illustrates, SBI group made major improvement in *Structural Matching* in the posttest, and then declined slightly in the delayed posttest. Comparatively, the META+SBI group declined slightly in the posttest, and then increased significantly in the delayed posttest. As

demonstrated, the trend of the two treatment groups on the *Structural Matching* dimension was similar to that of the *Graphical Matching* dimension.

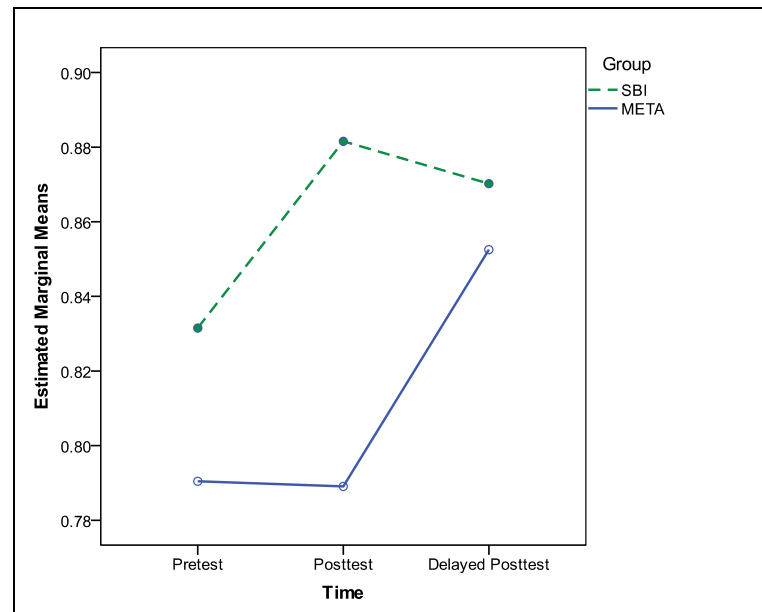


Figure 16. Main study concept mapping performance in Structural Matching

Considering the two treatment groups' significant differences in the science EB pretest, a repeated-measures MANCOVA was conducted with students' total score of the science EB pretest as a covariate. No significant time, treatment, or Treatment x Time effect was found. Follow-up univariate tests did not find any significant effect.

Research Question 2: Do students' general epistemological beliefs have an effect on conceptual change during simulation-based inquiry learning as well as metaconceptually-enhanced simulation-based inquiry learning?

Multiple linear regression analysis was performed to answer this question. Before conducting multiple regression, visual inspections of residual errors suggested that the assumptions of linearity and homogeneity of variance were met. Kurtosis and skewness for each variable was within the reasonable range which indicated that the normality

assumption was met. Regarding the multicollinearity assumption, tolerance statistics ($> .10$) and VIF values (< 10) indicated that the assumption was met.

Predictors of the students' multiple-choice conceptual posttest scores were entered in the following hierarchical order: pretest score, scores on the five general EB dimensions, treatment group, and General EB x Treatment interaction term. In the first step, the pretest was a significant predictor of the conceptual posttest, $R^2 = .12$, adjusted $R^2 = .11$, $F(1,122) = 16.10$, $p < .01$. In the second step with added general EB dimensions, both pretest and general EB were significant predictors of the posttest, R^2 change = .12, $F(6,117) = 6.13$, $p < .01$. Specifically, there were three significant predictors: pretest, $b = .48$, $p < .01$, beliefs about the speed of knowledge acquisition (Speed), $b = -.14$, $p < .05$, and beliefs about the structure of knowledge (Structure), $b = -.14$, $p < .05$. In the third step with added treatment group factor, four significant predictors emerged: pretest, $b = .42$, $p < .01$, Speed, $b = -.14$, $p < .05$, Structure, $b = -.13$, $p < .05$, and treatment group, $b = 2.56$, $p < .01$. In this step, R^2 change = .13, $F(7,116) = 9.86$, $p < .01$. In the last step, General EB x Treatment interaction did not predict significantly over and above the previous models.

Table 10 shows the correlations among the variables, and Table 11 presents the summary of the regression analysis.

Table 10.

Correlations between Regression Analysis Variables in the Main Study

Variable	1	2	3	4	5	6	7	8	9
1. Posttest	—	.34**	-.35**	-.26**	-.13	-.11	-.17*	.43**	.04
2. Pretest		—	-.25**	-.07	-.13	.07	-.07	.11	.09
3. EB Speed			—	.26**	.09	.43**	.40**	-.08	-.06
4. EB Structure				—	-.25**	.34**	.22**	-.02	.14
5. EB ConMod					—	.01	-.17*	-.16*	.05
6. EB Success						—	.23**	-.02	.08

7. EB Truth	—	-.03	-.06
8. Treatment group		—	.04
9. Treatment x EB			—

* $p < .05$; ** $p < .01$

Table 11

Summary of Hierarchical Regression Analysis for Variables Predicting Conceptual Posttest in the Main Study

Predictor	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>p</i>
Step 1 ($R^2 = .12$)					
Pretest	.67	.17	.34	4.01	.00**
Step 2 ($R^2 = .24$, $\Delta R^2 = .12$)					
Pretest	.48	.17	.25	2.85	.005**
EBS-Speed	-.14	.07	-.22	-2.21	.03*
EBS-Structure	-.14	.06	-.23	-2.51	.013*
EBS-ConMod	-.08	.05	-.14	-1.62	.11
EBS-Success	.05	.08	.06	.62	.54
EBS-Truth	-.07	.13	-.05	-.51	.61
Step 3 ($R^2 = .37$, $\Delta R^2 = .13$)					
Pretest	.42	.15	.22	2.74	.007**
EBS-Speed	-.14	.06	-.22	-2.34	.02*
EBS-Structure	-.13	.05	-.21	-2.57	.011*
EBS-ConMod	-.04	.05	-.08	-.99	.32
EBS-Success	.05	.08	.06	.66	.51
EBS-Truth	-.05	.12	-.03	-.40	.69
Treatment group	2.56	.51	.37	4.98	.00**
Step 4 ($R^2 = .37$, $\Delta R^2 = .00$)					
Pretest	.42	.16	.21	2.70	.008**
EBS-Speed	-.14	.06	-.21	-2.30	.02*
EBS-Structure	-.13	.05	-.22	-2.58	.01*
EBS-ConMod	-.05	.05	-.08	-1.02	.31
EBS-Success	.05	.08	.06	.64	.52
EBS-Truth	-.05	.12	-.03	-.38	.70
Treatment group	2.55	.52	.37	4.94	.00**
Treatment x EB	.01	.04	.03	.34	.74

* $p < .05$; ** $p < .01$

Research Question 3: Does each of the instructional approaches, simulation-based inquiry learning approach and metaconceptually-enhanced simulation-based inquiry learning approach, have an effect on students' science epistemological beliefs respectively?

Table 12 shows the means and standard deviations of the four science EB dimensions.

Table 12

Means and Standard Deviations of Science EB Survey

Instruments (Subscales)	META+SBI		SBI	
	Pretest	Posttest	Pretest	Posttest
Source	9.80 (3.29)	8.78 (3.60)	10.53 (4.06)	9.86 (4.04)
Certainty	10.78 (3.28)	11.45 (4.64)	13.02 (4.57)	12.03 (4.30)
Develop	9.75 (3.54)	9.91 (4.54)	11.97 (4.00)	11.84 (4.38)
Justify	14.51 (4.51)	15.70 (5.25)	17.24 (5.09)	17.72 (5.50)

To examine the pretest-posttest change of science EB within each of the individual treatment groups (META+SBI or SBI), paired-sample t-tests were conducted. For the META+SBI group, scores on the *Source* beliefs significantly decreased between pretest ($M = 9.80$, $SD = 3.29$) and posttest ($M = 8.78$, $SD = 3.60$), $t(66) = 2.52$, $p < .05$, which suggested that the META+SBI group became more mature in their beliefs about the source of science knowledge. For the SBI group, their beliefs about the *Certainty* of science knowledge became more mature between pretest ($M = 13.02$, $SD = 4.57$) and posttest ($M = 12.03$, $SD = 4.30$), $t(57) = 2.59$, $p < .05$.

To compare the two treatment groups' science EB while controlling the science EB pretest, MANCOVA was conducted on all the science EB dimensions with the total score of the science EB pretest as a covariate. Box's M test indicated that the homogeneity assumption was met, Box's $M = 7.56$, $p > .05$. Multivariate tests did not show any significant group difference, $F(4, 119) = 1.24$, $p = .30$, $\eta^2 = .04$. Follow up univariate tests did not reveal any significant group difference in the four science EB dimensions.

Overall, while the two treatment groups each made significant improvement in one of the dimensions in science EB (*Source* for the META+SBI group and *Certainty* for the SBI group), no significant difference was found between the two groups when taking their science EB pretest into consideration.

Discussion

Built on the pilot study, this main study was conducted at a different school in formal science classes with a larger sample size. The study continued to examine the effect of metaconceptually-enhanced simulation-based inquiry on students' conceptual change and science EB, as well as the influence of learners' general EB on conceptual change. While some changes were made to the instructional materials and intervention, the research design in the main study was similar to that in the pilot study. Different from the pilot study, the two treatment groups in the main study had significant difference in science EB at the very beginning while there was no significant group difference in content knowledge. This section discusses the findings in response to each of the research questions.

Treatment Effects on Conceptual Change

In this study, it was hypothesized that both the SBI and the META+SBI groups would make significant improvement in conceptual change, and that the META+SBI group would outperform the SBI group because of the additional metaconceptual intervention that was intended to promote conceptual change. The findings only partially supported the initial hypotheses.

Students' performance in the multiple-choice conceptual tests was as expected. Both treatment groups made significant improvement in the conceptual posttest. While

there was a slight drop in the delayed posttest, the change was insignificant. More importantly, the META+SBI group outperformed the SBI group, as demonstrated by the significant interaction effects between treatment and time. Even with the consideration of the students' science EB pretest, the time, treatment, and interaction effects were still significant. Since the conceptual test focused on measuring specific misconceptions, it was therefore inferred that simulation-based inquiry helped to reduce misconceptions, and that the additional metaconceptual intervention was even more powerful in reducing students' misconceptions when compared with simulation-based inquiry alone. The findings were consistent with some previous studies (Biemans & Simons, 1995; Hennessey, 2003; Tao & Gunstone, 1999a; Vosniadou, 2003), which indicated the potential benefits of metaconceptual intervention, although few of them studied metaconceptual thinking exclusively as an intervention.

It is noted that, different from the META+SBI group in the main study, the same group in the pilot study did not perform better than the SBI group in the conceptual test. The improved performance of the META+SBI group in the main study could be attributed to the improvement made to the simulation guide and the additional interventions added to the main study. An examination of student records in the database revealed that the majority of the students in the main study answered most of the questions presented by the simulation guide whereas the majority of the students in the pilot study answered very few questions. Therefore, by working and interacting with the questions, the students in the main study were not only able to engage in inquiry tasks, such as making predictions, performing experiments, and drawing conclusions, but more importantly, they were able to actively engage in metaconceptual thinking. At the

beginning of their inquiry, they were led to realize the importance of questioning and checking their ideas, and to understand how simulation helped to test one's ideas. As they approached an investigation, they were prompted to become aware of their preconceptions and explain the reasoning behind the conceptions. Throughout the inquiry cycle, the students monitored the incoming new information from experiments, experts, or other sources, consciously checked against their own ideas, and made revisions as they deemed necessary. At the end of an investigation, students were led to critically evaluate the status of their understanding and reflect on any change to their beginning ideas. The metaconceptual intervention helped the students to purposely reflect on their conceptual knowledge, which might have led to the significant reduction of their misconceptions.

On the other hand, compared to their significant improvement in the conceptual test, the students' performance on the concept mapping test was not as positive as expected. When the students' differences in the science EB pretest were not taken into account, both groups were shown to have made significant improvement in *Graphical*, *Propositional*, and *Structural Matching* dimensions. Further, the SBI group outperformed the META+SBI group in *Structural Matching*. However, if the students' differences in the science EB pretest were considered, the META+SBI group did not show any advantage over the SBI group in any of the five concept mapping dimensions. Since using science EB as a covariate could not completely equate the two nonequivalent groups – other confounding variables might exist. The effects of enhancing simulation-based inquiry with metaconceptual intervention on changing one's cognitive structure remain inconclusive.

On the other hand, it is worth discussing the initial significant effects on the *Propositional*, *Graphical*, and *Structural Matching* dimensions, as well as the possible role science EB might have played in accounting for these significant effects. There are two possible reasons for the initial significant findings. First, similar to what was speculated in the pilot study, the META+SBI group might have focused their cognitive resources on processing the additional information provided by the metaconceptual simulation guide. As discussed earlier, the metaconceptual intervention in this study targeted individual concepts and the relationships between two concepts, rather than the overall relationships among multiple concepts. To use a *tree* vs. *forest* metaphor, the intervention focused more on the *tree* rather than on a broader, *forest* level. Thus the META+SBI students might have developed better understanding about individual concept (i.e., the *trees*), but might have not dedicated sufficient cognitive resources to reflect on the overall relationships among the key concepts that they had learned (i.e., the *forest*). Comparatively, the SBI group did not need to dedicate cognitive resources to process additional information provided by the metaconceptual simulation guide, thus the cognitive demand on the SBI group might not be as much as the demand on the META-SBI group. As a result, they were more likely to see the overall relationships among multiple concepts.

The second reason for the initial significant findings is related to the META+SBI students' more mature science EB. The META+SBI students might not readily accept new information and reconcile it with their existing cognitive structure, because this group of students had stronger beliefs that (a) not everything from a science book or other authority was true (i.e., the *Source* beliefs), (b) knowledge was subject to change with

new evidence (i.e., the *Development* beliefs), and (c) knowledge was of personal construction through experiments and reflection (i.e., the *Justification* beliefs).

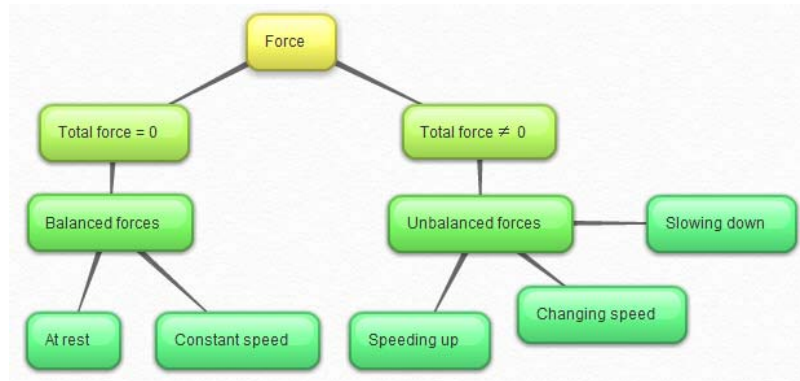
Consequently, it might have taken the META+SBI students more processing time before they were able to construct all that they had learned as a coherent whole. Comparatively, the SBI students might have been more ready to accept the new knowledge because of their more naïve epistemological beliefs (e.g., authority is the source of knowledge; knowledge is fixed; the justification of knowledge requires little personal construction).

Linking the above two reasons to the students' concept map performance, first we see that both treatment groups made significant improvement in *Propositional Matching* in the posttest, which is a semantic, *tree*-level measure that examines the number of correct propositions (concept-link-concept) in a concept map. The two groups' improvement in *Propositional Matching* was consistent with their significant improvement in the multiple-choice conceptual test.

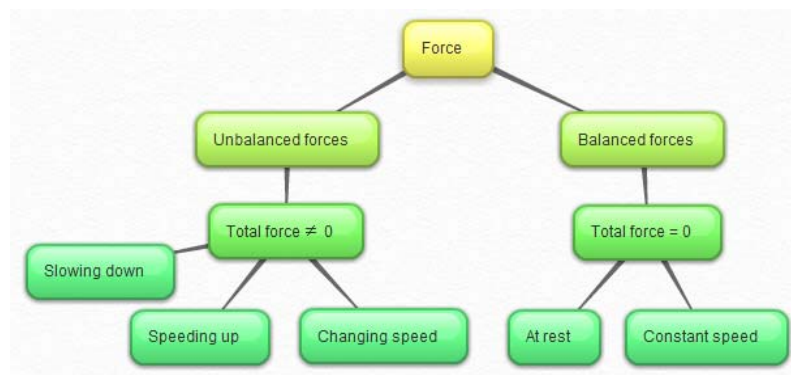
Secondly, on the *Structural Matching* dimension, which examined the overall structure of a concept map (at the *forest* level), the two groups exhibited different trends. While the SBI group students made significant improvement in the posttest, the META+SBI group did not make significant improvement. This trend was very similar to the findings of the pilot study on the same measure, and also corroborated with another structural measure in this study – *Graphical Matching*, which exhibited a similar trend. As discussed earlier, the META+SBI group's lack of improvement on this measure might be due to the lack of cognitive resources to conceptualize at the *forest* level as well as the time needed for this group to personally make sense of and integrate the new knowledge. Therefore, although the META+SBI group made more correct propositions in the posttest

(as demonstrated by the significant time effect on *Propositional Matching*), the propositions were not assembled correctly (as demonstrated by a lack of improvement in *Structural* and *Graphical Matching*). In other words, synthetic models were built (Vosniadou & Brewer, 1992). Similar results were found in Bråten, Strømsø, and Samuelstuen's (2008) study in which after reading multiple expository texts, those students who held more mature beliefs about the source of knowledge and viewed learning as personal construction showed poorer understanding than those with more naïve beliefs.

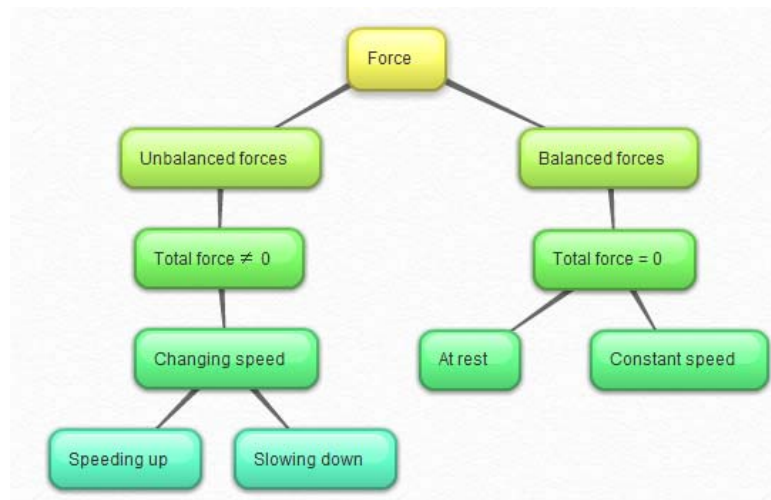
While Bråten et al. (2008) did not study students' performance in the delayed posttest, this study revealed the intriguing findings that the META+SBI group made significant improvement four weeks after the intervention, as demonstrated by the group's significantly improved *Structural* and *Graphical matching* performance in the delayed posttest. Less cognitive demand of learning tasks, more personal knowledge construction through reflection, and the lagging effects of metaconceptual intervention might have contributed to the students' continued restructuring of their mental models, which resulted in a more holistic mental structure of the key concepts that they had learned. Possibly, the concept mapping posttest might have served as a metaconceptual intervention which caused the META+SBI group to reflect more on the relationship among the 10 key concepts. Furthermore, the possible events in which they were able to apply some of what they had learned in the subsequent unit might have also triggered metaconceptual thinking among this group of students.



(a) Concept map in the pretest



(b) Concept map in the posttest



(c) Concept map in the delayed posttest

Figure 17. The concept maps of a META+SBI student: (a) the pretest, (b) the posttest, and (c) the delayed posttest.

Figure 17 shows the concept maps of a META+SBI student in the pretest, posttest, and delayed posttest, whose performance represented the trend of the META+SBI treatment group. Table 13 shows the scores of three dimensions of interest: *Propositional*, *Structural*, and *Graphical Matching*.

Table 13

The Pretest, Posttest, and Delayed Posttest Scores of a META+SBI Student's Concept Maps

Concept Map Scores	Pretest	Posttest	Delayed Posttest
Propositional Matching	.22	.78	1.00
Structural Matching	.86	.86	1.00
Graphical Matching	.86	.86	1.00

As shown in Table 13, the student's *Structural* and *Graphical Matching* scores did not change from the pretest to the posttest. A close examination of the student's concept map created in the pretest and the one created in the posttest revealed that the structures of the two maps were very similar. This could explain why the student's overall mental models, did not show much improvement right after the intervention. Having said that, the student's *Propositional Matching* score increased from .22 to .78, which indicated that the student built more correct propositions in the posttest concept map. As shown in Figure 17(a), in the concept map created by the student in the pretest, the *Force* concept was linked to two concepts – *Total force = 0* and *Total force ≠ 0*, and the two concepts were subsequently linked to two other concepts: *Balanced forces* and *Unbalanced forces*. While such a relationship was plausible, it did not serve to illustrate that it is the balanced or unbalanced forces that determined the amount of total force

(equal to or not equal to 0). In the posttest concept map, the student rearranged some concepts: *Force* was linked to *Balanced forces* and *Unbalanced forces*, which were subsequently linked to *Total force = 0* and *Total force $\neq 0$* . The posttest concept map revealed that the student improved his understanding about the causal relationships among the concepts. Further, the new structure, as demonstrated in Figure 17(b), also made it clear that it was the amount of total force that determined the different motions of an object (e.g., at rest, speeding up, etc.).

Four weeks after the intervention, the same student was able to construct a concept map that completely resembled the expert concept map, as shown in Figure 17(c) (also available in Appendix F). The delayed posttest concept map indicated significant improvement in *Structural* and *Graphical Matching*, as well as continued improvement in *Propositional Matching*. It is assumed that during the four-week period, the student was able to reconceptualize the relationships among the 10 concepts. While this particular student achieved the expert level in delayed posttest, those META+SBI students who did not achieve the expert model might continue to improve beyond the delayed posttest, given the trajectory of the group's growth.

To summarize, several conclusions can be drawn in regard to the treatment effect on the students' conceptual change: (a) While simulation-based inquiry led to the significant reduction of misconceptions, enhancing simulation-based inquiry with additional metaconceptual intervention led to greater reduction of misconceptions; (b) the respective effects of metaconceptual intervention and simulation-based inquiry on learners' cognitive structure are still unclear; (c) students' science EB might influence the effect of metaconceptual intervention on students' construction of mental models.

Specifically, more mature science EB could result in disequilibrium in one's cognitive structure right after the intervention, yet it could also facilitate continued effort and improvement in cognitive restructuring.

Effects of General EB on Conceptual Change

In this study it was expected that (a) certain dimensions of general EB would be significant predictors of the students' multiple-choice conceptual posttest, and (b) epistemologically more advanced students would benefit more from the META+SBI intervention. The findings supported the first expectation but not the second one.

Specifically, beliefs about the *speed of knowledge acquisition* (the *Speed* dimension) and the *structure of knowledge* (the *Structure* dimension) were found to be significant predictors of the students' conceptual change. The findings were consistent with the existing studies. In Qian & Alverman's (1995) study, which used refutational text to promote conceptual change, the researchers found two significant predictors of the students' conceptual change: *quick learning* and *simple-certain knowledge*, which were equivalent to the *Speed* and *Structure* dimensions in this study.

This study also extended the findings from the pilot study by revealing that the *Speed* and *Structure* dimensions of EB are specific predictors of conceptual change. Therefore, the study suggested that the more a student thought that learning was quick and that additional study time would not contribute to learning, the less likely the student was to spend time and effort on conducting simulation-based inquiry. Similarly, students who tried to avoid ambiguity as much as possible and always sought the single correct answer would not try to reflect on some puzzling findings that might challenge their

preconceptions. In both cases, the students were not likely to identify and revise their misconceptions, resulting in poor performance in the conceptual test.

On the other hand, this study found that epistemologically more mature students did not benefit more from the metaconceptual intervention as expected. This finding was consistent with the pilot study. While some studies speculated that there was a possible relationship between EB and metaconceptual thinking (Fulton & Kendeou, 2009; Stathopoulou & Vosniadou, 2007), the findings from both the pilot and the main studies failed to support such a speculation. The reason for the findings could be that students who are more epistemologically mature might be engaged in more metaconceptual thinking by nature, regardless of whether they received metaconceptual intervention or not. In other words, the metaconceptual intervention might not have much added value to students who are more epistemologically mature.

Treatment Effect on Science Epistemological Beliefs

In this study, while it was expected that both the SBI and the META+SBI conditions would have positive effects on developing students' science EB, it was speculated that the META+SBI condition would further promote students' science EB in comparison with the SBI condition. However, the findings only partially support the expectations.

The META+SBI group significantly improved in only one dimension of the science EB – the *Source* beliefs, which suggested that after the intervention the META+SBI group developed stronger beliefs that authorities, such as books, teachers, or scientists, were not the only sources of science knowledge. The SBI group, on the other hand, made significant improvement in another science EB dimension – the *Certainty*

beliefs, indicating that the SBI condition had led the students to believe more strongly that science knowledge is not always true and does not always have one right answer. The comparison between the two groups in science EB did not reveal any significant difference, suggesting that the additional metaconceptual intervention did not promote the META+SBI group's science EB as expected. The findings were different from Conley et al (2004) findings that inquiry learning improved students' *Source* and *Certainty* beliefs. Similar to what was discussed in the pilot study, the relatively short intervention time could be one of the reasons for the contradictory findings.

The findings from the main study were also different from the pilot study, in which the META+SBI group significantly outperformed the SBI group in both the *Source* and the *Certainty* dimensions whereas the SBI group did not improve in any science EB dimension. Several possible reasons might help to explain the inconsistent findings. First, the general student characteristics between the pilot study and the main study were different. A number of students from the science inquiry classes in the pilot study did not seem to be interested in science. However, in the main study the students were recruited from the general science classes, and they represented a more diverse group with a wider range of interest in science. Further, as mentioned earlier, the students from the two schools had different experiences with inquiry learning (e.g., the students in the pilot study had been exposed to inquiry-based learning while the students in this study had little experience with inquiry-based learning). Altogether, the differences in the students' characteristics between the two schools might have contributed to the different patterns in the students' development of science EB.

The second reason for the different findings between the pilot study and the main study might be due to a set of revisions made to the intervention in the main study. For example, compared with the SBI students in the pilot study, the simulation-based mini-inquiry in the main study might have helped to engage the SBI students in science inquiry processes. As they were constructing their own knowledge and building their own theory, the students might have become more mature in their beliefs about the certainty of science knowledge. Yet, it was unclear why the META+SBI students in the main study did not show development in their beliefs about the certainty of science knowledge.

The third possible reason for the different findings between the two studies might be that the two treatment groups in the main study had different science EB at the very beginning. Although statistical analysis could partial out the pretest difference, the results could not account for the different development patterns, which might show up in the two groups with different starting points.

Finally, the small sample size in the pilot study and the resulting low power might have also contributed to the different findings between the two studies.

CHAPTER 5: DISCUSSION AND CONCLUSION

As this country is making STEM education its top priority (National Science Board, 2007), conceptual change and the development of mature epistemological beliefs have become two important goals in science education (Pintrich, et al., 1993; Sinatra, 2005; Vosniadou, 2007b; Vosniadou & Brewer, 1992). Conceptual change is related to students' entrenched preconceptions that interfere with what they learn in the science classroom. Although not explicitly studied in the literature, it is expected that metac conceptual thinking, an active mental process of keeping aware of and monitoring one's conceptual understanding, is likely to promote conceptual change (Murphy & Mason, 2006; Vosniadou, et al., 2001).

Learning science is not only about acquiring science content knowledge, but more importantly developing mature beliefs about the ways of knowing and the nature of knowledge in science, that is, science epistemological beliefs. However, students often hold naïve science epistemological beliefs, and they often do not think like scientists. Existing literature postulates that epistemological beliefs may have two layers – at the fundamental level are domain-general beliefs about knowledge and learning, and as individuals grow with life experience and education, domain-specific epistemological beliefs become more dominant (Buehl & Alexander, 2001; Muis, et al., 2006). Some studies have found that a learner's general epistemological beliefs may have an impact on conceptual change (Qian & Alvermann, 1995; Windschitl, 1997), and that science epistemological beliefs may be malleable to instructional interventions such as inquiry learning (Conley, et al., 2004; Kienhues, et al., 2008; Smith, et al., 2000). Further, there

may be a possible relationship between epistemological beliefs and metaconceptual thinking (Lam & Chan, 2008; Stathopoulou & Vosniadou, 2007).

Situated in a simulation-based inquiry learning environment, the current research aimed at investigating how students' general epistemological beliefs, metaconceptual intervention, simulation-based inquiry, and the interaction between the beliefs and the intervention contribute to students' conceptual change and the development of science epistemological beliefs. Two studies (i.e., the pilot study and the main study) were conducted to answer the three research questions. This section first provides an overview of the convergent findings, which is followed by a discussion of implications for research. This section ends with a discussion about the limitations of the study.

Overview of Findings

Metaconceptual intervention enhanced simulation-based inquiry learning by significantly reducing students' science misconceptions.

In the pilot study, the META+SBI group did not show significantly fewer misconceptions than the SBI group. One of the major reasons was that many students were not engaged in metaconceptual intervention. After modifications were made to the main study, the META+SBI group demonstrated significantly fewer misconceptions than the SBI group in both posttest and delayed posttest. Therefore, it was concluded that the metaconceptual intervention was able to enhance simulation-based inquiry learning.

As research indicated (Murphy & Mason, 2006; Vosniadou, et al., 2001), students often lack metaconceptual thinking when learning science, and this can interfere with conceptual change. While engagement in inquiry tasks has potential to help students construct knowledge and build their own theories, students often do not consciously

examine their own ideas and monitor the development of those ideas as they perform inquiry tasks. Therefore, in this study metaconceptual intervention was systematically implemented to the META+SBI group in order to stimulate the students' metaconceptual thinking during the process of simulation-based inquiry. Compared with the SBI students who performed typical science inquiry tasks, the META+SBI students acquired metaconceptual knowledge (e.g., one's idea is subject to check, the idea can change with new evidence) and engaged in metaconceptual processes as they were prompted to become aware of their own ideas, monitor new information from other sources, and evaluate their new understanding. As a result, the META+SBI group in the main study showed significantly fewer misconceptions than the SBI group.

Metaconceptual intervention did not facilitate immediate change of broad knowledge structure, but may have potential delayed effect.

While metaconceptual intervention was effective in reducing misconceptions, it did not do as well in changing students' knowledge structure, that is, their mental models of the interrelated key concepts in a given topic they were studying. In both the pilot study and the main study, the metaconceptual intervention either did not improve students' concept mapping performance, or led to the students' poorer posttest performance in *Structural Matching*. As speculated in earlier discussions, the reason for the META+SBI group's lack of improvement in the posttest might be that (a) the metaconceptual intervention was mostly focused on helping the students to build local, propositional knowledge rather than a broader network of multiple interrelated concepts, (b) there might be a certain level of cognitive demand associated with the mental processing of metaconceptually-enhanced simulation guide. These two factors might

have resulted in the META+SBI students' lack of sufficient cognitive resources to conceptualize a bigger knowledge structure.

On the other hand, four weeks after the intervention, the META+SBI students in the main study improved in several structural dimensions of concept mapping, which suggested that the metaconceptual intervention might have potential delayed effects. However, given that the two groups were nonequivalent in the main study, the speculated delayed effect requires more empirical evidence.

Beliefs about the speed of learning and the construction of knowledge affected students' correction of misconceptions in science inquiry learning.

Both the pilot study and the main study confirmed the relationship between students' general EB and their learning performance. While the pilot study found that the students' general EB was a significant predictor of the conceptual change, the main study pinpointed the specific dimensions – beliefs about the *speed of knowledge acquisition* and beliefs about the *construction of knowledge*. Therefore, the findings suggested that when students worked on science inquiry, their beliefs about the speed of learning and the construction of knowledge determined whether they were likely to take time to perform inquiry tasks, examine findings, question their understanding, and correct potential misconceptions.

More epistemologically mature students did not necessarily benefit more from metaconceptual intervention than their less mature counterparts.

Some studies found that more epistemologically mature students tended to demonstrate more metaconceptual thinking (Fulton & Kendeou, 2009; Stathopoulou & Vosniadou, 2007), which indicated a possible relationship between epistemological

beliefs and metaconceptual thinking. This study set out to investigate whether more epistemologically mature students would benefit more from metaconceptual intervention. In both studies, the original speculation was not supported. Students across different epistemological levels equally benefited from the metaconceptual intervention.

The effects of simulation-based inquiry and metaconceptual intervention on students' science epistemological beliefs were inconclusive.

Inquiry learning has been found to promote science EB (Conley, et al., 2004; Smith, et al., 2000). Further, there was also beginning evidence that continuous engagement in metaconceptual thinking might promote one's epistemological development (Wyre, 2007). Therefore, this study investigated whether the SBI students would show improvement in science EB, and whether the META+SBI group would demonstrate more mature science EB than the SBI group. This study showed inconsistent findings.

In the pilot study, the META+SBI group became significantly more mature than the SBI group in their beliefs about the *source* and *certainty* of science knowledge, while the SBI group did not show any pretest-posttest improvement in science EB. However, in the main study the META+SBI group showed improvement only in their beliefs about the *source* of science knowledge, while the SBI group became more mature in their beliefs about the *certainty* of science knowledge. No significant difference in science EB was found between the two groups in the main study.

Given the inconsistent findings, limited treatment time, and the significant group difference in science EB pretest found in the main study, the effects of simulation-based

inquiry and metaconceptual intervention on the development of science EB remained inconclusive in this study.

Theoretical Implications and Future Research

Conceptual Change

In quantitative research on conceptual change, the learning outcomes were often conceptualized and measured as the number of corrected misconceptions. This study took advantage of the HIMATT technology to quantitatively examine the changes occurring to both students' misconceptions and their mental models. The inclusion of the concept mapping assessment allowed the researcher to zoom out the lens from local misconceptions to a broader cognitive structure that consisted of multiple concepts and their interrelationships. While the study confirmed the effectiveness of simulation-based inquiry and metaconceptual intervention on reducing students' misconceptions, it also revealed the inadequacies of the intervention on the change to the broader cognitive structure. As found in the study, while the students demonstrated over-time improvement in multiple-choice conceptual test, their concept mapping performance did not make simultaneous improvement.

This study demonstrated that conceptual change is a multi-faceted process. As illustrated by the earlier analyses of concept map findings, as the students revised their misconceptions and built more correct individual propositions in their cognitive structure, the propositions might not be assembled correctly to form a coherent, holistic knowledge representation. Successful conceptual change, in the context of this study, should be a process during which learners build more correct propositions and in the meantime

assemble the propositions in a structure that resembles the knowledge structure of the experts.

Future research should try to use multiple measures to assess conceptual change in order to obtain a more holistic picture of the students' conceptual change learning outcomes. Focus should be placed on the changes to learners' cognitive structure, by using both quantitative research method to examine trends and make comparisons, and by using qualitative approaches to track the developmental process of learners' knowledge structure. It would also be interesting to examine the linkage between the revisions of misconceptions and the changes to the overall cognitive structure. Finally, studies on how students use the restructured knowledge in problem solving situations will also shed light on the transfer of conceptual change learning outcomes.

Epistemological Beliefs

Several theoretical implications were drawn from this study to inform research on epistemological beliefs. First, learners' general epistemological beliefs have significant effect on the extent to which one revises initial misconceptions in a simulation-based inquiry learning environment. Particularly, learners' beliefs about the speed of learning and the construction of knowledge act like a thinking disposition that affects how they work with computer simulations and perform inquiry tasks which lead to the revision of misconceptions.

Second, this study confirmed that science epistemological beliefs are malleable with appropriate instructional intervention. Traditionally epistemological beliefs have been treated as a stable, trait-like construct that develops only with years of experience and education. Researchers have just begun to explore ways to promote the development

of students' science epistemological beliefs with instructional intervention (Conley, et al., 2004). This quantitative study demonstrated that students' beliefs about *source* and *certainty* of science knowledge improved as the result of the intervention. On the other hand, learners' beliefs about the *development* and *justification* of science knowledge did not have significant change in this study. One of the explanations could be that the nature of the inquiry tasks and activities in this study were relatively well-structured. Students were asked to follow the procedure to investigate pre-defined topics, and they did not have much opportunity to freely conduct science inquiry. As a result, these inquiry activities did not have enough influence on students' beliefs about the justification and development of science knowledge.

Thirdly, this study provided more evidence about the multilayered framework of epistemological beliefs. In the main study where the two treatment groups had significant difference in their science epistemological beliefs, their general beliefs were at a similar level (except for one dimension). The findings suggested that while more students in the META+SBI group participated in accelerated science classes, the science classes appeared to have more impact on the students' science epistemological beliefs than on their general beliefs. Therefore, it is inferred that individuals' general epistemological beliefs are relatively stable over time, and that science epistemological beliefs are more susceptible to instructional interventions.

Finally, as found in the main study, when pretest science epistemological beliefs were included as a covariate, the significant effects on several concept map measures were no longer significant. The findings indicated that the maturity of students' science

epistemological beliefs might be a factor that influenced the effect of metaconceptual intervention on the students' concept mapping performance.

Based on the theoretical implications, future research should explore the ways to promote students' mature science epistemological beliefs, especially the beliefs about *development* and *justification* of science knowledge. Interventions such as ill-structured science inquiry activities, discussions, and team activities can provide more opportunities for argumentation, elaboration and reflection, which contribute to the development of science epistemological beliefs. Studies with a longer period of treatment time will be particularly helpful in examining the intervention effects. Furthermore, clinical interviews can be used to complement quantitative surveys to address the psychometric weaknesses of epistemological belief instruments, and to provide better understanding about students' epistemological beliefs and their relationship with treatment and conceptual change. Finally, it is worth further investigation on whether science epistemological beliefs interact with metaconceptual intervention in influencing the change to learners' mental models. For example, it remains to be confirmed whether more epistemologically advanced learners need more time to process metaconceptual intervention and reconcile new knowledge with their existing knowledge.

Metaconceptual Thinking

Since Yuruk et al. (2008) advanced the theoretical framework for metaconceptual thinking, this study represented one of the first efforts to systematically implement metaconceptual intervention to examine its effects on conceptual change. The findings from this study provided explicit evidence that the additional metaconceptual intervention was able to enhance simulation-based inquiry by significantly reducing learner

misconceptions. In the mean time, the findings also revealed the complexities related to the effects of metaconceptual intervention in influencing the change of learners' mental models; for instance on some concept map measures, the learners performed poorer in the posttest, but later improved in the delayed posttest.

The findings led to speculations about the possible cognitive demand associated with metaconceptual intervention, which might interfere with the students' immediate learning outcome. The findings also revealed a lack of emphasis on a broader cognitive structure in the current metaconceptual framework. Specifically, metaconceptual intervention should zoom out from individual concept level to help students (a) develop metaconceptual knowledge, that is, conceptual learning involves a network of interconnected ideas, (b) become aware of their understanding about key concepts and their interrelationships, (c) monitor how new information integrates into individuals' existing mental models, (d) construct and evaluate new mental models.

The theoretical implications provided directions for future research on metaconceptual thinking. Future studies should pay attention to facilitating students' metaconceptual thinking about multiple interrelated concepts and consequently investigate the intervention effect on students' mental models. Discussions, group activities, and concept mapping learning exercises can be used to promote students' metaconceptual thinking.

For future research, the study design must be carefully examined and improved to ensure that the META+SBI students' learning outcomes are indeed influenced by the metaconceptual intervention, and not by any other factors, such as cognitive demand or motivation. There are several alternatives to approach this issue and improve the design.

First, the level of cognitive demand of the SBI group can be matched with that of the META+SBI group by having the SBI group perform additional, but content-irrelevant learning activities. Second, students' levels of metaconceptual thinking can be measured as a manipulation check. For example, a questionnaire can be designed to elicit students' self-perceived level of metaconceptual thinking as a result of intervention. Alternatively, students' responses to metaconceptual questions in the simulation guide can provide rich context and information to help researchers better understand the nature and the effect of metaconceptual intervention. Students' qualitative responses can be rated based on the demonstrated levels of metaconceptual thinking. In both cases, students' metaconceptual thinking can be quantified, which will allow researchers to identify those who indeed demonstrate metaconceptual thinking as a valid pool for further investigation. In this way, researchers will be able to more accurately examine the linkage between metaconceptual intervention, metaconceptual thinking, and conceptual change.

Lastly, in this study metaconceptual thinking was used mainly as a means to promote students' conceptual change. One of the instructional goals for future studies is to help students who are less metaconceptual to become more metaconceptual through metaconceptual intervention. Research should explore the development of metaconceptual thinking as a learning goal itself. In other words, an important goal of metaconceptual intervention should be developing students' *habit of mind* to examine and monitor their metaconceptual thinking even when metaconceptual support is not available. In addition, future studies should examine students' learning progress and outcome in metaconceptual thinking not only immediately after an intervention, but also at a delayed time when the metaconceptual scaffold is no longer available.

Implications for Science Education

Enhance Science Inquiry Learning with Metaconceptual Intervention

Inquiry learning has been advocated in science education, but emphasis has been placed on facilitating the process of making predictions, conducting and observing experiments, and drawing conclusions. While these processes are essential to help students actively build knowledge, they do not effectively address students' misconceptions. Without intentional monitoring of individuals' conceptual thinking, students are not likely to be aware of the inconsistencies between their misconceptions and the information coming from other sources during the inquiry process. In other words, with inquiry learning alone, conceptual change is difficult to achieve.

Therefore, teachers may encourage students to become more aware of the nature of conceptual learning, that is, students need to possess a certain level of metaconceptual knowledge. Further, during students' inquiry learning, the teacher should systematically promote students' metaconceptual awareness, monitoring, and evaluation. As demonstrated in this study, question prompting can be an effective strategy. For instructional designers who design and develop inquiry-based learning materials, metaconceptual components should be purposely built in the process of inquiry. The metaconceptual intervention framework illustrated in Table 2 can serve as a reference in designing and facilitating students' metaconceptual thinking.

To provide more focused and individualized intervention, it is recommended that metaconceptual intervention be aligned with diagnosis and assessment. In both classroom and web-based learning, assessment tools can be developed to diagnose students' specific misconceptions, and metaconceptual intervention can be provided according to individual

needs. A linkage and alignment between misconception, intervention, and assessment has potential to reduce students' misconceptions and enhance their metaconceptual thinking.

Promote Metaconceptual Thinking on Broader Cognitive Structure

One of the weaknesses of the metaconceptual intervention in this study was the lack of emphasis on helping students conceptualize a broader cognitive structure. Therefore, while facilitating students' science inquiry learning and metaconceptual thinking, science teachers should encourage students to consider a conceptual framework that consists of the key concepts they have learned. The teacher can explicitly prompt students to consider the relationships among the key concepts, or let students construct concept maps using the key concepts. Similarly, instructional designers can identify the key concepts in learning materials and use question prompts, concept mapping, or other learning activities to encourage students not only to build correct propositions in their mental models, but also to assemble the propositions appropriately to form expert-like mental models.

Provide Scaffolding for Inquiry Learning and Metaconceptual Intervention

As found in the pilot study, when implementing inquiry learning and metaconceptual intervention, students were not instantly oriented to new ways of learning. They might not know how to answer metaconceptual questions; they might not know they were supposed to link prediction, observation, and explanation in a systematic way; and they might not know the role simulation plays in inquiry learning. They needed more guidance and support to be able to perform the inquiry tasks more effectively. Therefore, explicit information, examples, modeling, and some mini-inquiry exercises, whether

provided in person or through computer-based learning materials, can prepare students to understand the nature of inquiry and to interact well with metaconceptual intervention.

Furthermore, in simulation-based inquiry learning, especially in a web-based environment, if an instructor is not available to facilitate learning, students' independent inquiry runs the risk of going off-track – they may misinterpret information, lack knowledge to conduct an experiment in a simulated environment, or miss some important steps. When this happens, the students may not be able to encounter an anomalous experiment result which was intended to refute students' misconceptions. In such circumstances, providing expert feedback and video demonstrations illustrating the appropriate way to conduct the experiment can help students to stay on track.

Promote Students' Epistemological Beliefs

As demonstrated in this study, epistemological beliefs play significant roles in conceptual change. While general epistemological beliefs may take time to develop, science epistemological beliefs are malleable and can be shaped by relatively short intervention. In this study, two weeks of inquiry activities were able to promote change in certain aspects of science epistemological beliefs. For these reasons, science teachers should make it an explicit goal to develop students' science epistemological beliefs in their daily teaching practice. While the intervention in this study was not able to improve students' beliefs in the *development* and *justification* of science knowledge, effort should be made to effectively address these two aspects in science education. Two types of learning activities may have high potential to promote the *development* and *justification* dimensions of science EB: (a) long-term interventions that allow students to work on more ill-structured inquiry tasks in which they can initiate their own ideas and put them

to the test; (b) collaborative inquiry activities that provide opportunities for students to work with peers to elaborate their ideas, negotiate meaning, justify thinking, and develop theories.

Alternate Methods of Learning to Sustain Student Motivation

From the pilot study it was found that students' motivation level dropped when only one delivery method was used. In the main study with planned sequence of teacher-guided and students' independent inquiries, the students stayed more on task and showed more engagement. Therefore, for both science teachers and instructional designers, in order to sustain student motivation, variety should be planned in instruction. The method of learning can alternate between instructor-led inquiries and students' independent inquiries. Other learning activities such as discussions and group work can also be helpful. While changing the format of learning, it is important for students to review previous sessions before starting a new session in order to ensure the continuity and consistency between different formats of learning.

Limitations of the Study

Due to the researcher's attempt to conduct the study in a naturalistic setting in order to gain more ecological validity, several accommodations were made in order to address the constraints in the school settings. The following are some noticeable limitations in this research.

First, in both the pilot and the main study, it was almost impossible to carry out random assignment of participants to the two treatment conditions, as required by a rigorous experimental study. Therefore, a quasi-experimental study was conducted. With intact classes assigned to one of the treatment conditions, significant pretest group

differences could have confounded the results of the studies. Further, the naturalistic school settings introduced various factors which might affect the study, for example, student absences, occasional events (e.g., a fire drill), and other extraneous factors.

Secondly, because of the same constraints in the school setting, a true control group (e.g., a regular science class) was not available to establish a baseline in order to gauge how well the two treatment groups performed in comparison with a regular science class.

Third, ideally a relatively longer period of time was required to investigate and answer the research questions. For example, the development of science epistemological beliefs is likely to take more than two weeks of time. However, the time limit in this study did not allow the researcher to implement longer intervention and examine the effects.

Fourth, as discussed earlier, this study lacked the measurement of metaconceptual thinking as a manipulation check. Therefore, the validity of study findings can be further improved by measuring students' levels of metaconceptual thinking, which would ensure that the differences in the students' learning outcomes were indeed influenced by the metaconceptual intervention.

Fifth, the inquiry activities in this study were relatively well-structured. Students did not have sufficient room for free inquiry, which might have resulted in the students' lack of development in their beliefs about the development and justification of science knowledge. With sufficient time for intervention, the inquiry activities could have been designed to be more ill-structured which would allow students to explore and experiment with their own ideas. In this way the researcher could also have the opportunity to

examine the effects of ill-structured science inquiry activities on students' conceptual change and science epistemological beliefs.

Lastly, this study took a quantitative approach with little qualitative data to enhance findings. The HIMATT quantitative data, for example, were based on complex computer calculations and thus the findings from the data were not as direct and easy to interpret as visual inspections of concept maps. Rich qualitative data could have provided more insights into the research findings, especially the unexpected results.

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APPENDIX A: PASS STANDARDS ADDRESSED IN THE INTERVENTION

The following eighth-grade PASS standards on science processes and physical science are relevant to this study:

Process Standard 1: Observe and Measure - Observing is the first action taken by the learner to acquire new information about an object, organism, or event. Opportunities for observation are developed through the use of a variety of scientific tools. Measurement allows observations to be quantified. The student will accomplish these objectives to meet this process standard.

Process Standard 2: Classify - Classifying establishes order. Objects, organisms, and events are classified based on similarities, differences, and interrelationships. The student will accomplish these objectives to meet this process standard.

Process Standard 3: Experiment - Experimenting is a method of discovering information. It requires making observations and measurements to test ideas. The student will accomplish these objectives to meet this process standard.

Process Standard 4: Interpret and Communicate - Interpreting is the process of recognizing patterns in collected data by making inferences, predictions, or conclusions. Communicating is the process of describing, recording, and reporting experimental procedures and results to others. Communication may be oral, written, or mathematical and includes organizing ideas, using appropriate vocabulary, graphs, other visual representations, and mathematical equations. The student will accomplish these objectives to meet this process standard.

Process Standard 5: Inquiry - Inquiry can be defined as the skills necessary to carry out the process of scientific or systemic thinking. In order for inquiry to occur, students must have the opportunity to ask a question, formulate a procedure, and observe phenomena. The student will accomplish these objectives to meet this process standard.

Physical Science Standard 2: Motions and Forces - The motion of an object can be described by its position, direction of motion, and speed. The student will engage in investigations that integrate the process standards and lead to the discovery of the following objectives:

2. The motion of an object can be measured. The position of an object, its speed and direction can be represented on a graph.
3. An object that is not being subjected to a net force will continue to move at a constant velocity (in a straight line and a constant speed) (Oklahoma State Department of Education, 2009).

APPENDIX B: SAMPLE SIMULATION GUIDE

- B1: Sample Simulation Guide for the SBI Treatment Group
- B2: Sample Simulation Guide for META+SBI Treatment Group

Investigation 2: Position-Time Graph for At-Rest Object

Part 3 of 3



Activity 3: Predicting Position from Position Graph

So far we have examined the position graphs for objects that stand still at different positions. How about the other way around - if you were given an object's position graph, can you tell the object's motion from the graph?



Predict

The **Position** graph below shows the motion of a car.



Can you predict the car's motion from the above **Position** graph? Make your selection below.

- ☐ A. The car is running steadily from left to right .
- ☐ B. The car is at rest.
- ☐ C. None of the above.



Observation

- Open the Moving Man simulation. **Turn off** the *Velocity* and *Acceleration* graphs, leaving only the **Position** graph open.
- Use the *Position* slider and the **Go** button to make a position graph that looks like the one above. Observe the movement of the man to see if your prediction is correct.

Feel free to play with the Moving Man simulation if you want to explore more. Once you are done, you have finished this investigation! You may click the **Next** button to enter the next investigation.

Investigation 2: Position-Time Graph for At-Rest Object

Part 3 of 3



Activity 3: Predicting Position from Position Graph

So far we have examined the position graphs for objects that stand still at different positions. How about the other way around - if you were given an object's position graph, can you tell the object's motion from the graph?



Predict

The **Position** graph below shows the motion of a car.



Can you predict the car's motion from the above **Position** graph? Make your selection below.

- ☐ A. The car is running steadily from left to right .
- ☐ B. The car is at rest.
- ☐ C. None of the above.



Click to Check Your Idea!

What is the reason for your prediction above? Explain your reason below.

The reason for my prediction is that

Zima thinks that **position-time graph** shows an object's moving path. She believes that the position graph above shows an object moving from left to right and so A is the correct answer. Do you agree with Zima?

- ☐ Yes, Zima's answer is correct.
- ☐ No, Zima's answer is wrong.





Observation

- Open the Moving Man simulation. **Turn off** the *Velocity* and *Acceleration* graphs, leaving only the **Position** graph open.
- Use the *Position* slider and the **Go** button to make a position graph that looks like the one above. Observe the movement of the man to see if your prediction is correct.



Click to Check Your Idea!

Is what you found from the simulation the same as your earlier prediction?

- ☐ A. Yes, what I found from the simulation is the same as my prediction.
- ☐ B. No, what I found from the simulation is different from my prediction.

Can you explain to Zima what you found from the simulation and tell her whether her answer is right or wrong? Write down below what you want to say to her.

Zima, I think your answer is (right/wrong), because I found from the simulation that

As you reach the end of this investigation, think again about the **Big Ideas** in this investigation - **Position graphs** for **at-rest** objects. After your experiments, how different is your current idea from your beginning one? In the box below, write down the **biggest change** to your initial idea and how that happened.

Before I thought:
Now I learned from this investigation that

Feel free to play with the Moving Man simulation if you want to explore more. Once you are done, you have finished this investigation! You may click the **Next** button to enter the next investigation.

APPENDIX C: INSTRUMENTS

C1: Motion and Force Multiple-Choice Conceptual Test

C2: Motion and Force Concept Mapping Test

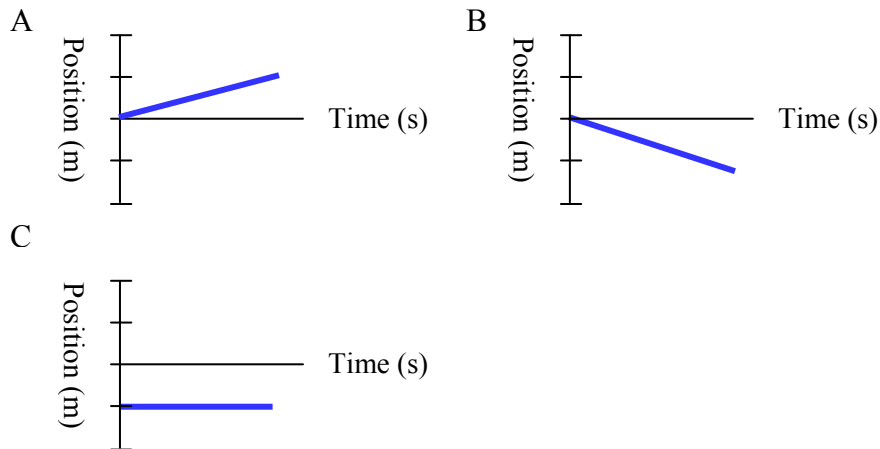
C3: Epistemological Beliefs Survey (adapted from Wood & Kardash, 2002)

C4: Science-Specific Epistemological Beliefs Survey (Conley, et al., 2004)

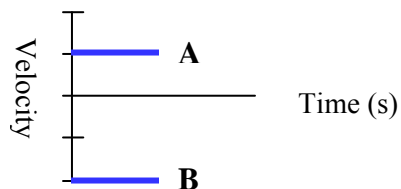
C1: Motion and Force Multiple-Choice Conceptual Test

Motion and Force Conceptual Test

1. A fire station receives a phone call that a building is on fire. The fire station is 5 miles to the west of the city center, and the distance between the city center and the building on fire is 10 miles. How far do the fire trucks have to travel before arriving at the building? (1*)
- A. 15 miles
B. 5 miles
C. There is no sufficient information to answer the question.
2. If an object is *at rest*, which of the following is a possible position-time graph for the object? If you think that none is correct, answer D. (Note: A position-time graph shows how an object's position changes with time) (3, 5)

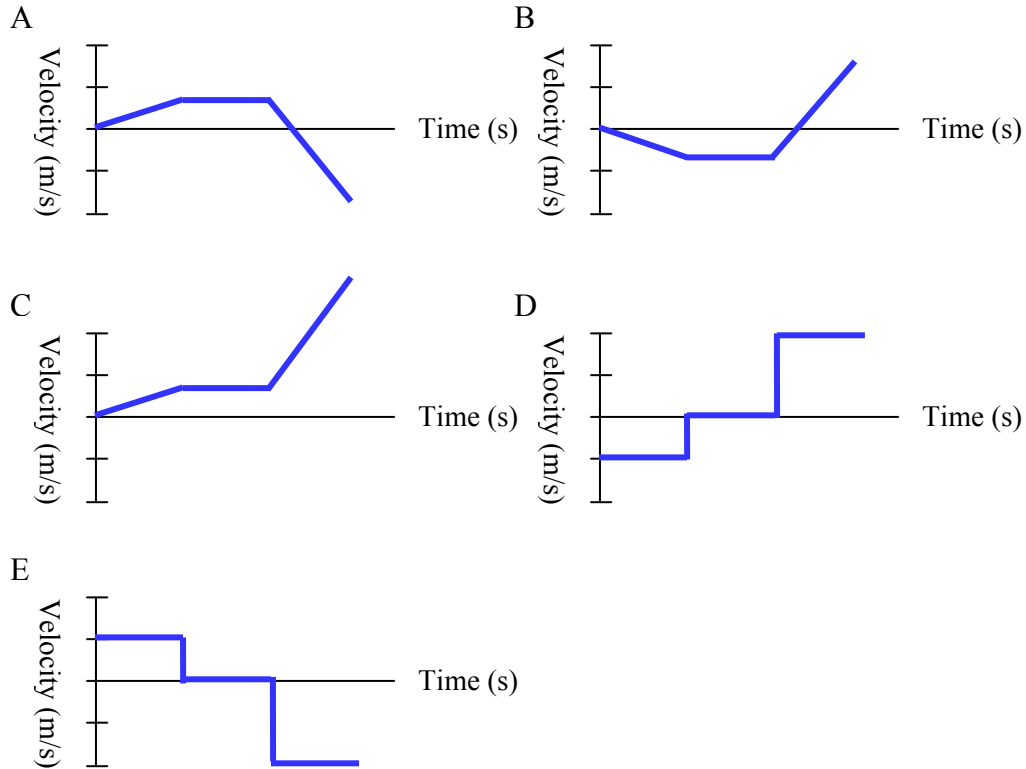


3. The following velocity-time graph shows the motion of two balls. Which of the statements below is true about the velocity of the two balls? (Note: A velocity-time graph shows how an object's velocity changes with time) (2, 3, 5)

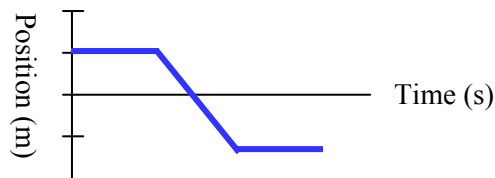


- A. A is rolling faster than B.
B. B is rolling faster than A.
C. A and B are rolling equally fast.
D. Both A and ball B are at rest.

4. A man starts at the origin, (1) walks to the left at a *slow, constant velocity* for 6 seconds, then (2) *stands still* for 6 seconds, and then (3) changes direction and walks to the right *twice as fast*, but still at a *constant velocity* for 6 seconds. Which velocity-time graph best depicts the man's movement? Suppose the *positive* direction is moving to the right. If you think that none is correct, answer F. (2, 3, 4, 5)



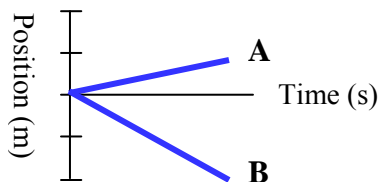
5. The position-time graph below shows how a ball's position changes with time. Which of the following correctly describes the ball's motion? (suppose the *positive* direction is moving forward) (2, 3, 4, 5)



- A. The ball moves along a flat surface. Then it moves forward down a hill, and then keeps moving.
- B. The ball moves along a flat surface. Then it moves backward down a hill, and then keeps moving.
- C. The ball is moving at constant velocity. Then it slows down and stops.
- D. The ball doesn't move at first. Then it moves forward down a hill and finally stops.

E. The ball doesn't move at first. Then it moves backwards and then finally stops.

6. The following position-time graph shows how the positions of two balls, A and B, change with time. Which of the statements below is true about the two balls' motion? (3, 5)

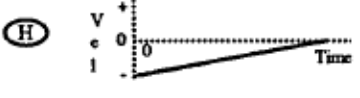
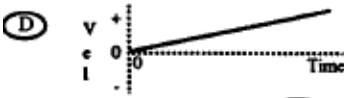
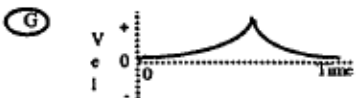
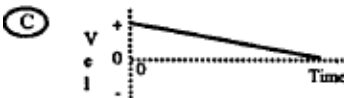
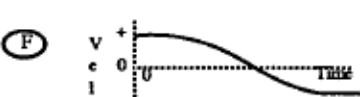
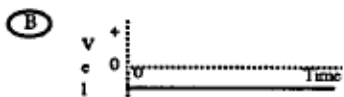
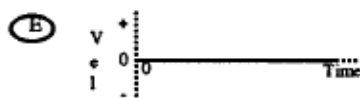
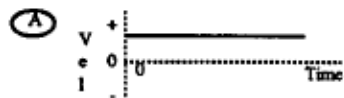


- A. A is rolling faster than B
- B. B is rolling faster than A
- C. A is speeding up more than B
- D. B is speeding up more than A.

Questions 7-10 refer to the following scenario:



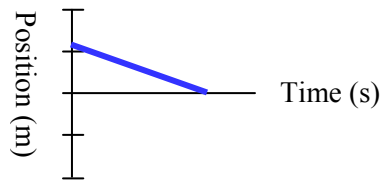
A toy car can move to the right or left along a horizontal line. The *positive* direction is to the right. Choose the correct velocity-time graph (A-H) for each of the following questions. You may choose a graph more than once or not at all. If you think that none is correct, answer J.



(J) None of these graphs is correct.

- 7. Which velocity graph shows the car moving toward the right at a steady (constant) velocity? (3, 4, 5)
- 8. Which velocity graph shows the car reversing direction? (3, 4, 5)

9. Which velocity graph shows the car moving toward the left at a steady (constant) velocity? (2, 3, 4, 5)
10. Which velocity graph shows the car increasing its speed at a steady (constant) rate? (3, 4, 5)
11. The position-time graph below shows the movement of a bowling ball down the alley. Which of the following correctly describes the ball's motion? (Suppose the *positive* direction is moving forward) (3, 4, 5)



- A. The ball is moving forward at a constant velocity.
 B. The ball is moving backward at a constant velocity.
 C. The ball is moving forward and slowing down steadily.
 D. The ball is moving backward and slowing down steadily.
 E. The ball is slowing down steadily down a hill.
 F. The ball is speeding up steadily down a hill.
12. A sports car and a school bus are both on the road running to the north. The sports car is running at a *constant velocity* of 60 miles per hour, and the school bus is running at a *constant velocity* of 40 miles per hour. Which of the following is true about the total force acting on each of the two cars? (Note: Total force is the sum total of all the forces acting on an object) (6, 9)
- A. The sports car has a larger total force on it.
 B. The school bus has a larger total force on it.
 C. The two cars have the same total force.
 D. There is not enough information to tell.
13. If an object does not move, there must be no force acting on it. (7)
- A. True
 B. False
14. If the total force on an object is zero (0), which of the following is true? (Note: Total force is the sum total of all the forces acting on an object) (8, 10)
- A. The object must be at rest.
 B. The object must be slowing down.
 C. The object must be moving at a steady (constant) velocity.
 D. The object must be either at rest or moving at a steady (constant) velocity.

Questions 15-16 refer to the following scenario:

David gave his shopping cart a push and then released the cart. The cart moved forward and gradually slowed down.

15. After David released the shopping cart, which of the following is correct about the horizontal force(s) acting on the cart? (11)
- A. The force from David's push
 - B. The friction force from the floor
 - C. Both of the above
 - D. None of the above
16. A large box is being pushed forward across the floor at a constant velocity. What can you conclude about the total force acting on the box? (6, 10)
- A. The total force must be 0.
 - B. The total force must be decreasing.
 - C. The total force must be constant.
 - D. The total force must be increasing.

Questions 17-18 refer to the following scenario:

A block is sitting on a table when a hand pushes it, giving it an initial velocity. The block starts to slide across the table. Suppose that we are in an ideal situation where the table has NO friction at all. In the image below, at state a, the hand is pushing block; at state b, the hand is no longer pushing the block.



17. For state b, which of the following correctly describes the block's movement on the frictionless table after the hand stops pushing it? (10, 11)
- A. The block will slow down steadily at constant acceleration until it stops.
 - B. The block will move steadily at constant velocity and will not stop.
 - C. The block will speed up steadily at constant acceleration.
18. For state b, which of the following correctly describes the horizontal force(s) acting on the block after the hand stops pushing the block? Remember the table has NO friction. (11)
- A. The force from the push
 - B. There is no force acting on the block
 - C. None of the above is correct

* The number(s) listed at the end of each question stem links to the misconception(s) listed below:

1. The location of an object can be described by stating its distance from a given point, ignoring direction.
2. Velocity must be positive, plotted above the time axis.

3. Students have difficulty relating real world motions to a graph and vice-versa.
4. Students plot position and velocity graphs as the path of the particle.
5. Students don't know which quantity in a graph will answer a question (coordinate or slope).
6. Constant velocity results from constant force.
7. If there is no motion, there must be no force.
8. If there is no force, there must be no motion.
9. Faster moving objects have larger force acting on them.
10. An object will slow down when the total force is zero.
11. When a force is removed from a moving object, it still has impetus on the object to keep it moving.

C2: Motion and Force Concept Mapping Test

Imagine that your younger brother, sister, or cousin becomes curious about cars and how they can move in different ways, like speeding up, slowing down, or running smoothly (at constant speed). You try to use what you know about motion and force to explain to him/her the reason of different forces that make a car move in different ways. Suppose you are given the following concepts, each of which is written on a sticky note.

1. Force
 2. Car at rest
 3. Balanced force on the car
 4. Unbalanced force on the car
 5. Total force on the car = 0
 6. Total force on the car $\neq 0$
 7. Car running at constant speed
 8. Car changing speed
 9. Car slowing down
 10. Car speeding up
- Try to arrange the sticky notes into a map that represents the relationship between the concepts. The purpose is to use the map to explain to the younger kid what makes a car move in different ways.
 - Next, use your pencil to draw a line between any two notes that you think are connected.
 - Lastly, explain the link you draw between any two notes. What is the reason for you to link two sticky notes? What is the relationship between the concepts written on the two notes? Write down the relationship.

C3: Epistemological Beliefs Survey

The following statements are about your beliefs about *knowledge and learning*. Please indicate how strongly you agree or disagree with each of the statements listed below. Please select the number that best describes the strength of your belief. There is no right or wrong answer.

Strongly Disagree-----Strongly Agree

1 5

1. You can believe most things you read.
2. Nothing we learn is certain.
3. If something can be learned, it will be learned immediately.
4. I like information to be presented straightforwardly; I do not like having to figure out myself the meaning behind.
5. It is difficult to learn from a textbook unless you start at the beginning and learn one part at a time.
6. Forming your own ideas is more important than learning what the textbooks say.
7. The first time you read a textbook is when you get almost all the information you can understand from the book.
8. A really good way to understand a textbook is to organize its information according to your own understanding.
9. If scientists try hard enough, they can find the answer to almost every question.
10. You should evaluate the accuracy of information in textbooks if you are familiar with the topic.
11. You will just get mixed up if you try to combine new ideas in a textbook with what you already know.
12. When I study, I look for specific facts.
13. If teachers would stick more to the facts and spend less time explaining theories, students could get more out of school.
14. To be a good student, you have to memorize a lot of facts.

15. Wisdom is not knowing the answers, but knowing how to find the answers.
16. Working hard on a difficult problem only pays off for really smart students.
17. Some people are born good learners; others are not.
18. If you do not understand something, going over it the second time usually won't help.
19. Successful students understand things quickly.
20. Today's facts may change tomorrow.
21. I really like teachers who organize their lessons carefully and then stick to their plan.
22. The most important part of scientific work is original thinking.
23. Even advice from experts should be questioned.
24. If I can't understand something quickly, it usually means I will never understand it.
25. I try to combine information from different chapters of textbook or even from different classes.
26. I don't like movies that don't have a clear ending.
27. Scientists can ultimately get to the truth.
28. It's a waste of time to work on problems that do not have a clear-cut answer.
29. Understanding main ideas is easy for good students.
30. It is annoying to listen to teachers who cannot seem to make their mind up about what they really believe.
31. A good teacher's job is to keep students from wandering off the right track.
32. A sentence has little meaning unless you know the situation in which it was spoken.
33. The best thing about a science class is that most problems have only one right answer.
34. Most words have one clear meaning.
35. The really smart students don't have to work hard to do well in school.
36. When I learn, I like to make things as simple as possible.

37. I find it exciting to think about issues that scientist can't agree on.
38. The things we learn in school will not change.

Adapted from Wood & Kardash (2002)

Scoring:

Speed: 3, 7, 11, 16, 18, 24, 34, 38

Structure: 4, 5, 12, 13, 21, 26, 28, 30, 31, 33, 36

ConMod (R): 2, 6, 8, 10, 15, 20, 22, 23, 25, 32, 37

Success: 14, 17, 19, 29, 35

Truth: 1, 9, 27

C4: Science-Specific Epistemological Beliefs Survey

The following statements are about your beliefs about *knowledge and learning*. Please indicate how strongly you agree or disagree with each of the statements listed below. Please select the number that best describes the strength of your belief. There is no right or wrong answer.

Strongly Disagree-----Strongly Agree

1 5

1. Everybody has to believe what scientists say.
2. In science, you have to believe what the science books say about stuff.
3. Whatever the teacher says in science class is true.
4. If you read something in a science book, you can be sure it's true.
5. Only scientists know for sure what is true in science.
6. All questions in science have one right answer.
7. The most important part of doing science is coming up with the right answer.
8. Scientists pretty much know everything about science; there is not much more to know.
9. Scientific knowledge is always true.
10. Once scientists have a result from an experiment, that is the only answer.
11. Scientists always agree about what is true in science.
12. Some ideas in science today are different than what scientists used to think.
13. The ideas in science books sometimes change.
14. There are some questions that even scientists cannot answer.
15. Ideas in science sometimes change.
16. New discoveries can change what scientists think is true.
17. Sometimes scientists change their minds about what is true in science.

18. Ideas about science experiments come from being curious and thinking about how things work.
19. In science, there can be more than one way for scientists to test their ideas.
20. One important part of science is doing experiments to come up with new ideas about how things work.
21. It is good to try experiments more than once to make sure of your findings.
22. Good ideas in science can come from anybody, not just from scientist.
23. A good way to know if something is true is to do an experiment.
24. Good answers are based on evidence from many different experiments.
25. Ideas in science can come from your own questions and experiments.
26. It is good to have an idea before you start an experiment.

Source: Conley et al. (2004)

Scoring:

Source: 1-5

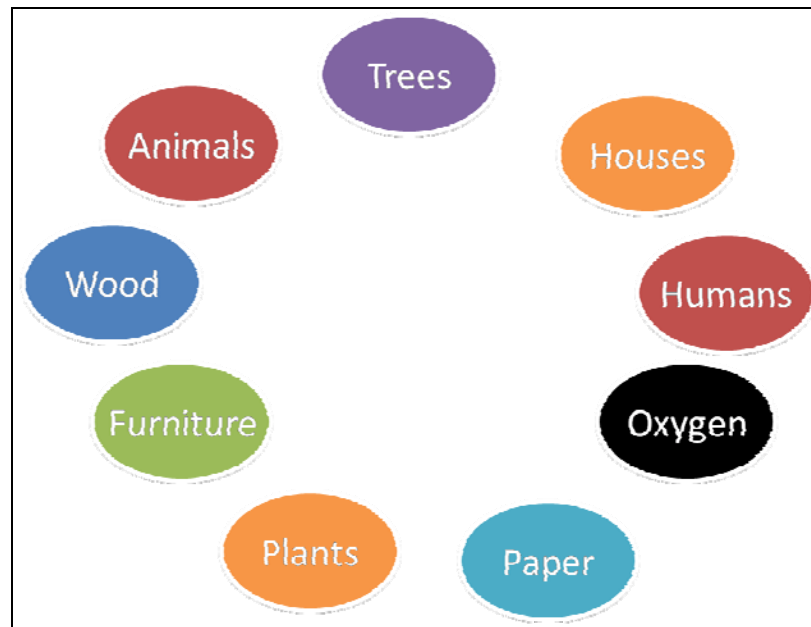
Certainty: 6-11

Development (R): 12-17

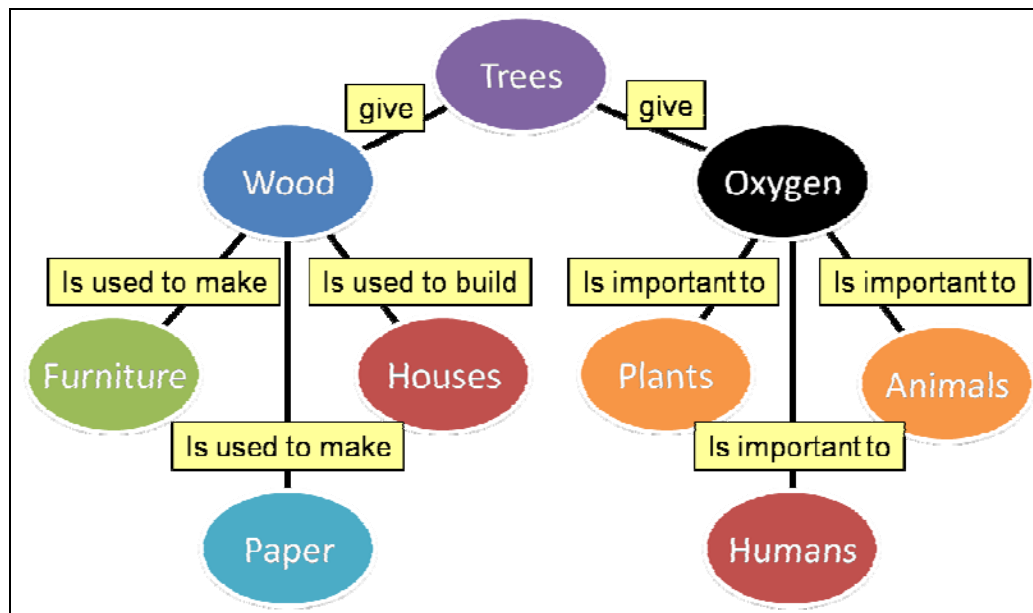
Justification (R): 18-26

APPENDIX D: EXAMPLE CONCEPT MAP FOR TRAINING PURPOSE

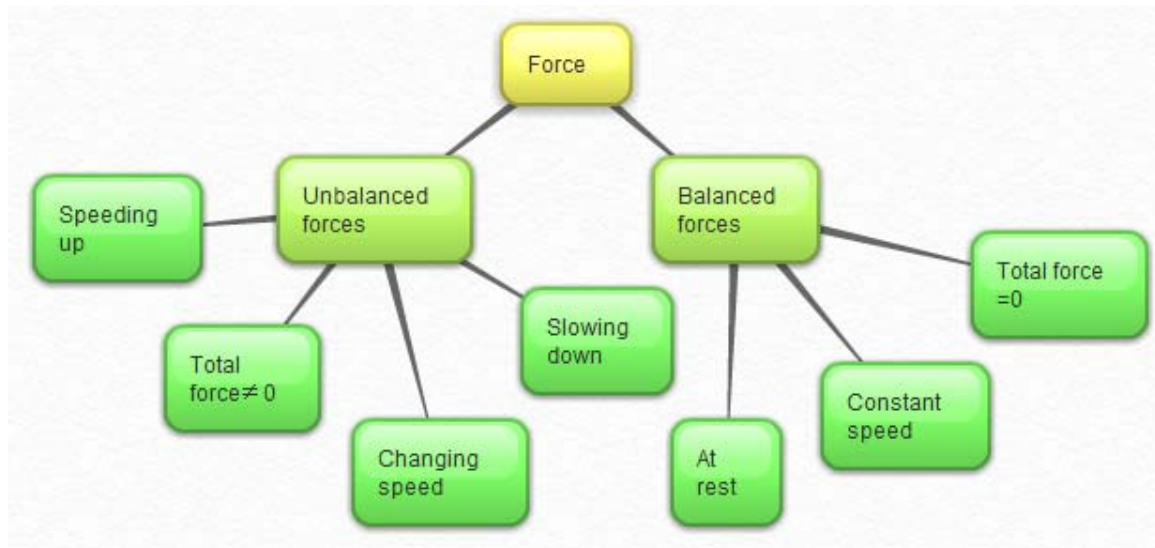
1. Example concepts (nodes) for student to practice concept mapping



2. Example concept map demonstrated at the end of the concept mapping training



APPENDIX E. SAMPLE CONCEPT MAP AND CORRESPONDING DATA ENTRY



	A	B	C	D	E
1	modID	node1	node2	vpn	mzp
2	135	A	C	441	2
3	135	A	B	441	2
4	135	C	J	441	2
5	135	C	E	441	2
6	135	C	H	441	2
7	135	C	I	441	2
8	135	B	F	441	2
9	135	B	G	441	2
10	135	B	D	441	2

Column heading	Description
modID	Every concept map is assigned a unique ID.
node 1 & node 2	Represent two linked pairs in the concept map. Each concept is labeled with a unique letter: A-Force, B- Balanced forces, C- Unbalanced forces, D-Total force=0, E-Total force≠0, F-At rest, G-Constant speed, H-Changing speed, I-Slowing down, J-Speeding up.
vpn	Represent the ID assigned to the student in this study.
mzp	Represent the measurement point: 1-pretest, 2-posttest, 3-delayed posttest

APPENDIX F: EXPERT CONCEPT MAP

